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NWC TP 5039
Part 4

Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert

Part 4. Tropics

Prepared for
Ordnance Systems Department

JULY 1989

NAVAL WEAPONS CENTER
CHINA LAKE, CA 93555-6001

Naval Weapons Center

FOREWORD

This report (Part 4) describes the tropical dump storage portion of a continuing effort to determine the thermal environment of dump-stored ordnance. Part 1 contains a summary of results for tropics and desert storage; Part 2, a sample of the raw data obtained by the Naval Weapons Center (NWC), China Lake, Calif.; and Part 3, data obtained from the desert dump storage portion of this effort. This effort was sponsored by the Naval Air Systems Command under the Guided Missile Propulsion Technology Block Program (AirTask A32-320G/008B/WF31-330-000). Mr. Lee N. Gilbert was the NWC technology administrator for this program.

The data collection and much of the preliminary writing necessary to prepare this report were performed by Howard C. Schafer prior to his separation from the Naval Weapons Center. The document was completed from his notes.

This report has been reviewed for technical accuracy by W. Parmenter and Crill Maples.

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31 July 1989

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Released for publication by
G. R. SCHIEFER
Technical Director

NWC Technical Publication 5039, Part 4

Published by . . . . Technical Information Department
Collation . . . . Cover, 50 leaves
First printing . . . . 400 copies

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT A Statement
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NWC TP 5039, Part 4	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Weapons Center; 6b OFFICE SYMBOL (If Applicable)	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code) China Lake, CA 93555-6001	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION Naval Air Systems Command; 8b OFFICE SYMBOL (If Applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Washington, D. C. 20361	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO A32-320G/008B/ WF31-330-000; WORK UNIT

11 TITLE (Include Security Classification)

Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert. Part 4. Tropics (U)

12 PERSONAL AUTHOR(S)

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	From TO	1989, July	98

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse side if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Environmental criteria determination; Tropical dump storage; Tropics-stored ordnance temperatures; Measurement techniques

20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

(U) Measurement sites were established in the tropics in Panama, Australia,and the Republic of the Philippines to obtain empirical data that could be used to more accurately predict the thermal environment of ordnance and material field stored in the tropics. Data obtained from these measurement sites are presented and analyzed. The data are presented in cumulative probability versus temperature format. The environmental criteria determination investigation at NWC covered a period of 15 years, and this report represents only a sample (5 million data points) of the information available covering the various events of the factory-to-target sequence.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Lee N.Gilbert	22b TELEPHONE (Include Area Code) 619-939-7206; 22c OFFICE SYMBOL 3205

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

CONTENTS

INTRODUCTION

Of the many events in the stockpile-to-target life (see Appendix A) of a weapon system (References 1-4), dump storage is possibly the most misunderstood. This lack of understanding has resulted in unrealistic design and qualification requirements that have increased the man-hours and costs of developing weapon systems and created problems in the middle-temperature range performance of most sophisticated tactical weapons. As part of the environmental criteria determination effort at NWC, empirical data have been obtained to more accurately predict the thermal environment of dump-stored ordnance.

In 1959, NWC recognized the need to develop thermal criteria for future weapon systems. In 1963 a task force was organized to investigate the total environmental criteria determination problem. In 1964, the Quality Assurance Division at NWC assembled a group of personnel who have continued to study these problems. First, the overall problem was analyzed to determine the most critical areas requiring immediate attention. The key area seemed to be the thermal environment during storage and transportation, since no meaningful analysis of humidity, precipitation, corrosion, vibration, or shock effects could be conducted without a thermal basis. Also, for the majority of naval material, 75-90% of the life of an item is spent in transportation and storage. Based on these facts, it was decided to conduct a concentrated study of the thermal regimes in the areas of transportation and storage on a worldwide basis.

Storage of naval material can be grouped into three major categories: covered, igloo, and dump, with igloo and covered storage of material being by far the most prevalent. A study was therefore conducted on the storage temperatures of explosive hazard magazines, and a series of technical reports was issued (References 5-10). In addition, a report summarizing all results obtained through 1971 was published (Reference 11). The work was completed in 1981 in a summary of worldwide conditions (Reference 12).

Although covered and igloo storage of naval material is most prevalent, dump storage generally results in the more extreme thermal exposure situations. (A detailed discussion of the dump storage situation is given in Appendix B.) Since no data were available on dump storage, instrumented storage dumps were established at representative locations around the world so that statistical data could be derived on a variety of ordnance items. Sites were established to sample the temperate and subarctic cold as well as the tropic and desert exposure situations. (This report, however, concerns itself solely with the results from three tropical dump storage sites: one located in the Republic of Panama, another in the Republic of the Philippines, and the third in Australia.)

One of the more misleading aspects of a statistically infinite worldwide dump storage measurement program such as described in this report is that the measured object must be exposed for years. The surfaces of such objects tend to degrade normally, but this degradation is more than should be expected from a like item when stored under combat conditions. In combat, the time of exposure before use is limited to a few days or weeks.

BACKGROUND

It has been recognized by the more forward looking design and project personnel that the whole area of the military environment has not been presented as a technology area. No body of formal education presently exists to prepare an environmentalist specializing in military field applications. Therefore, most of those who have function in this technology area, come to it without the necessary background. A second group functioning in this technology area includes the aerodynamicist, thermodynamicist, meteorologist, and statistician. These people have a good background in their particular disciplines, though not in the military environment. Hence, they tend to interpret questions in the context of their given technology.

It was in response to the need for expertise in the area of the military environment that the Naval Air Systems Command decided to sponsor a limited effort (Reference 13). The thrust of this effort was to develop environmental criteria determination and use into a technology area.

The path chosen to accomplish this was to develop the necessary tools and techniques. It was projected that these derived tools and techniques would be versatile enough so that, with a limited data base, most military material could be assigned meaningful environmental criteria even before being designed, based on basic physical parameters. It was advocated that the needed techniques, methods, nomographs, etc., be codified into updatable military handbooks.

PROCEDURES

ORDNANCE

The rocket motors and virtually all the other ordnance and material used in this extended measurement series were taken from Army, Navy and Air Force surplus inventories. These items were considered adequate for this purpose and representative of present and future hardware, when viewed in the thermodynamic context.

When a particular inert rocket motor was available, it was used intact; but, in the case of rocket motors, once-fired hardware was much more plentiful. However, to utilize the once-fired hardware, an inexpensive durable propellant simulant was needed. The chemistry staff of the NWC Ordnance Systems Department discovered that thoroughly dried desert blow sand would serve as such a simulant (a comparison of simulants is given in Appendix C).

Initially, all rocket motors used in this measurement series were cartridge-loaded, inert production motors. However, since the general rocket motor grain configuration of the future will probably be case-bonded rather than cartridge-loaded, most of the inert rocket motors added later were configured to simulate the case-bonded type motor. Use of the blow sand greatly facilitated this simulation and also reduced costs.

The following general observations are made about the ordnance used in the dump-storage program reported herein:

1. The ASROC rocket motors at all tropical sites are of the sand-filled type.
2. The Sparrow motors are all sand-filled.
3. The Sidewinder rocket motors contain production inert grains.
4. The 2.75-inch FFAR motors contain plastic simulant and are cartridge loaded.
5. About 50% of the Zuni (5-inch) motors are sand-filled, and about 50% are cartridge-loaded.

It is interesting to note that the resulting thermal data for any items smaller than 8 inches in diameter do not allow one to readily differentiate between the case-bonded and cartridge-loaded units. Apparently the differences in the masses of the units are so small that this point loses overall significance.

THERMOCOUPLES

Position

It was concluded early in the program that the highest temperature of an exposed missile (containerized or bare) was reached at the 12 o'clock position. A set of copper-constantan thermocouples was therefore positioned through the 12 o'clock position of the test item. A point halfway between the ends of the container was chosen for the thermocouple placement pattern in order to negate the moderating influence of thermal "end effects" (the result of heat escaping in all three dimensions from the surface of the container rather than just penetrating downward). In hot climates, these end effects are always responsible for the measurement of a "cooler" temperature in parts other than the central portion of the missile at the point of measurement. The center position was chosen only after measurements of a fully instrumented Sparrow sand-filled motor indicated that the effect was less pronounced at the center than within 1.5-2 calibers of the ends of the motor. The central portion of the motor was the most thermally stable and extreme and, therefore, universally used for the measurement series.

Construction

All thermocouples were copper-constantan (Type T). The hot junction for internal measurements was a welded or silver-soldered 1/16- to 1/18-inch-diameter ball. Two types of surface thermocouples were used for the shipping container or motor skin. The most universal and easiest to install was the area-averaging type, which consists of a 0.005-inch-thick, 1/4-inch-square copper plate. The constantan wire is silver-soldered to one corner and the copper wire to another corner, and the assembly is attached to the area of interest with epoxy.

Early in the program these thermocouple units were simply taped to the surface of interest. This attachment method was satisfactory for short times at locations at which the installation was regularly inspected for thermocouple liftoff. However, for long-term, abandoned-site measurements, this attachment method did not prove satisfactory. Another, more time consuming method was to

1. Drill two small holes about 1/8 to 1/4 inch apart in the surface to be measured.
2. From the underside, place the copper wire in one hole and the constantan wire in the other.
3. Silver-solder the wires in place.
4. Grind down the solder joints so the surface was again smooth.
5. Repaint.

Comparative data from both types of installation indicated no significant measurement difference for either application method.

Locations

Thermocouples were placed in, on, and throughout the various ordnance items. At the onset of this phase of the program there was little agreement as to the degree of difference of thermal response throughout the measurement matrix. Therefore, it was decided to use "too many" thermocouples rather than come up short. As an example, the original installation at the U.S. Army Fort Clayton measurement site in the Panama Canal Zone is detailed in Table 1. (As it turned out, reams of similar data existed for reporting purposes.)

Not all the data from these thermocouples were used in formulating the results presented in this report. First, no value was considered for use if it was suspect for any reason. Much data were rejected because of real or suspected recorder or thermocouple malfunction. Second, no reason was seen to include overlapping or similar data. Third, some data had either been published, or were in the process of publication, under different topics: truck-enclosed ordnance (Reference 14) and the NWC Thermal Standard (References 15-20).

Though the Table 1 example is for Panama, this basic procedure was used for the other sites. More or less ordnance might be exposed, but the principles of thermocouple placement, data quality, and display were standard.

TABLE 1. Thermocouple Locations at Fort Clayton Measurement Site.

Recorder No	Channel	Thermocouple	Measurement
9	1	1	Mk 82 bombs in truck (E-45)
	2	2	Mk 82 bombs in truck (W-45)
	3	3	10 mm in truck -- SW bottom
	4	4	10 mm in truck -- SW top
	5	5	120 mm in truck -- SW bottom
	6	6	120 mm in truck -- SW top
	7	7	120 mm in truck -- NE bottom
	8	8	120 mm in truck -- NE top
	9	9	Ambient air in truck
	10	10	Ambient air in Zuni case in truck
	11	11	Cased Zuni motor in truck (skin)
	12	12	Cased Zuni motor in truck (center motor)
	13	13	Mk 81 east side (skin)
	14	14	Mk 81 center top round (skin)
	15	15	Mk 81 west side (skin)
	16	16	Fuzes in container, bottom fuze
	17	17	Fuzes in container, top fuze
	18	18	Fuzes in container, center fuze of lot
	19	19	Amplifier tube
	20	20	Mk 82 center top round (skin)
	21	21	Mk 82 west side (skin)
	22	22	Mk 83 east side (skin)
	23	23	Mk 83 west side (skin)
	24	24	Mk 82 west side (inside)
11	1	25	Zuni pod, container (skin)
	2	26	Zuni pod, east bottom motor (skin)
	3	27	Zuni pod, west top motor (skin)
	4	28	Zuni pod, west top motor center
	5	29	Cased Zuni motor, container (skin)
	6	30	Cased Zuni motor, motor skin
	7	31	Cased Zuni motor, motor center
	8	32	Sparrow on stand, top (skin)
	9	33	Sparrow on stand, west (skin)
	10	34	Sparrow on stand, bottom (skin)
	11	35	Sparrow on stand, east (skin)
	12	36	Sparrow on stand, center
	13	37	Sparrow on stand, radome top
	14	38	Sparrow motor, container top
	15	39	Sparrow motor, motor skin
	16	40	Sparrow motor, motor center
	17	41	2.75 inch rocket, container (skin)
	18	42	2.75 inch rocket, east bottom motor skin
	19	43	2.75 inch rocket, west top motor skin
	20	44	2.75 inch rocket, west top motor center
	21	45	ASROC motor, container top
	22	46	ASROC motor, motor skin
	23	47	ASROC motor, motor center
	24	48	Amplifier tube, in recorder

TABLE 1. (contd.)

Recorder No.	Channel	Thermocouple	Measurement
	1	49	6 inch Projectile SE bottom
	2	50	6 inch Projectile SE top
	3	51	6 inch Projectile NW top
	4	52	6 inch Projectile NW bottom
	5	53	120 mm SW top
	6	54	120 mm SW bottom
	7	55	120 mm NE top
	8	56	120 mm NE bottom
	9	57	105 mm NE center
	10	58	105 mm SW center
	11	59	Small arms cases in ammo box, top row
12	12	60	Small arms cases in ammo box, center row
	13	61	Thermal Standard, top
	14	62	Thermal Standard, west
	15	63	Thermal Standard, bottom
	16	64	Thermal Standard, east
	17	65	Thermal Standard, center
	18	66	Inside air temp, No. 12 junction box
	19		Outside air temp, No. 12 junction box
	20		Air temp inside, No. 12 recorder
	21		Air temp east of instrument shack
	22		Air temp in instrument shack
	23		Reference junction, in recorder
	24		Amplifier tube, in recorder

INSTRUMENTATION

Recorders

The measurement instrument was the Honeywell Model 15 Universal 24-point stripchart recorder. This instrumentation mode has been state-of-the-art for at least 45 years. The manufacturer's advertised accuracy is 0.25% of the full-scale measurement range (-100 to +250°F). For this measurement series, this accuracy represented an error margin of less than 1°F. None of the more than 30 instruments used in this measurement series exceeded this overall error band.

Some problems resulted because these Honeywell recorders--which are essentially laboratory instruments not intended for field use--were abandoned on-site for months at a time. Since they were not serviced for periods of 3 months to 1 year, failures had to be kept to a minimum through preventive maintenance. Data were recorded for 60 days with the recorder unattended before personnel had to change the stripchart roll.

Because of the relatively slow sample rates necessary, slow temperature changes encountered, and low narrow band of temperature sampled in this type of sequence, normal thermocouple and instrument errors either were not encountered or were classified as "in the noise."

Data Reduction

During the first few years, a complete program of data reduction was followed. But costs were prohibitive and the number of data channels being reduced had to be decreased. As a first step, therefore, only daily maximum and minimum temperatures were considered. This method indicated the "extreme" days, so that complete data for any of those days could be obtained when desired. However, since this method left much to be desired for any type of statistical treatment, it was later decided to reduce a representative sample of the Honeywell chart data, but for all channels. The majority of the cumulative probability displays presented herein were derived in this way. Appendix D of NWC TP 5039, Part 3 (Reference 21) describes the procedure for statistical handling of data.

Data Presentation

In the early years of this effort, any field measurement usually consisted of a few days' to a few weeks' worth of data. It is easy to present 50 to 100 data points in a coherent, workmanlike manner, but not as easy to do the same with over 5 million data points covering a nominal 34 recorder years worth of information. As stated in Part 1 of NWC TP 5039, pages 21 and 22 (Reference 22), the next method usually used was to plot a line per channel per day and to join the maximum and minimum data points. This solved the problem for those interested in large field measurement efforts, but did not indicate the difference in the amount of time spent from the center of that maximum-minimum temperature bar to the minimum data point from the lesser amount of time spent from the center to the maximum point. Also, there is no indication of the "risk" that is taken if any arbitrary temperature design value is chosen. In this report, therefore, the solution is to present a statistically infinite amount of data in plots of general probability versus temperature. The majority of the following data figures can be read directly to provide a "risk" or "assurance" value for any temperature chosen. The figures are plotted to enable the assurance value to be read directly. To convert from assurance to risk, all one has to do is subtract the assurance value from a value of one.

Figure 1 shows a typical diurnal temperature profile as measured on and in ordnance that is stored in a tropical location. This tropical

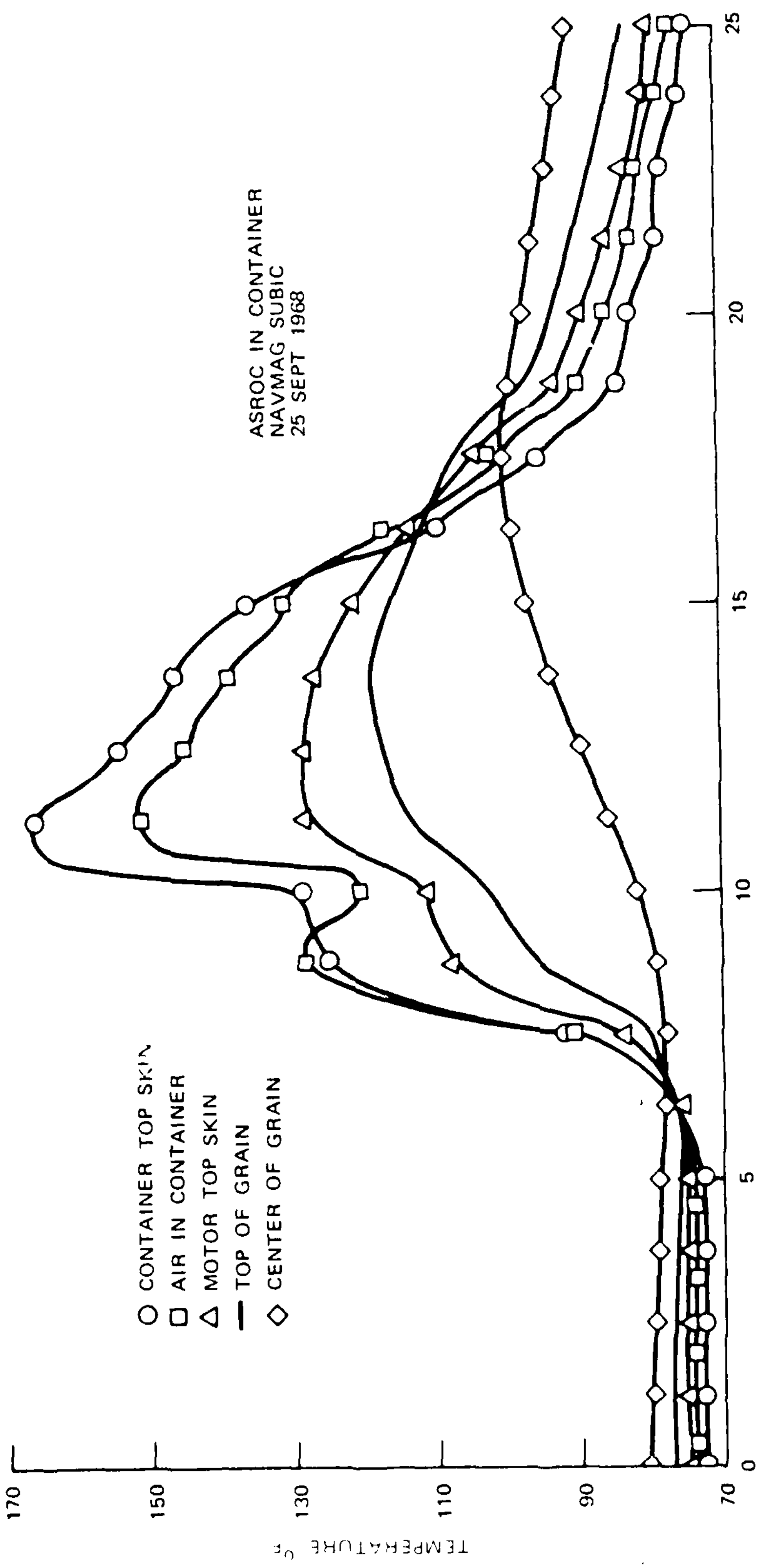

FIGURE 1. Typical Profile of Time of Day Versus Temperature.

display is not a typical representation; many years worth of data were culled to provide such a smooth display. (The reason that a diurnal temperature plot is not usually a smooth curve for tropically stored ordnance is that winds, clouds, rain and other meteorological phenomena exist and can affect the presentation.) A more detailed discussion of the less than yearly data displays for ordnance and material stored in the open in the tropics is provided in the "ASROC Data" section in Part 1 of NWC TP 5039, (Reference 22), pages 18-37. There, even monthly cumulative probabilities are shown in figure form, and the rationale is presented on which they were plotted. Also, an example of the complete digitally displayed data from which dump storage cumulative probability curves are derived is provided in Part 2 of NWC TP 5039 (Reference 23), which contains all the computer data sheets relating to the ASROC example in Part 1.

DUMP STORAGE IN THE TROPICS

The selection of tropical dump storage sites was made in view of the realities of jungle and combat situations. The environmental problems involved in establishing a tropical dump storage site include vegetation, soil, insects, and humidity. Also, since material is not dump stored in the tropics unless it is of tactical necessity, the problems arising in a combat situation are pertinent. Combat dump storage at Da Nang and Chu Lai in Vietnam, as well as storage at Guam and other jungle sites, was studied for data on tropical dump storage problems. Details on the problems of the combat situation and the jungle environment are provided in Appendix D.

The data described in this report can be viewed as "conservative." This is so because real world dump storage thermal data differ from the data presented later in this report. In a working storage dump, ordnance is not singly stacked, but as much as can be placed in the least volume is the norm. However, all the thermal measurements were taken on single units, single four-round units, or only a pallet of ordnance. Since the larger the mass, the less severe the thermal profile will be, the combat situation is less severe than the conditions used for thermal data collection.

DUMP STORAGE MEASUREMENT SITES

Although covered and igloo storage of naval material is most prevalent, dump storage generally results in the more extreme thermal exposure situations. (A discussion of the dump storage situation is given in Appendix B.) Since no data were available on tropical dump storage, instrumented storage dumps had to be established at representative tropical locations on a worldwide basis so that statistical data could be derived on a variety of ordnance items. Again within the constraints of manpower and money, a system of measurement sites was developed.

The first site developed to obtain information on tropical exposure was requested by weapon projectile personnel. It was established in September 1966 at the naval base at Subic Bay, Republic of the Philippines. This was as close to Vietnam as was deemed advisable for taking measurements without interfering with the U. S. combat effort. Even so, it soon became apparent that the size and scope of this facility must remain limited. Although the naval magazine personnel were supportive of this effort, their work load, aside from this task, was so heavy that they could not devote much time to the effort. Figure 2 shows this measurement site. It returned between 36 and 53 channels of information for 5 years, or about 1.5 million data points. Figure 3 indicates the transitory nature of the ordnance measured here; the data might be for only a season or a year or it might be continuous for the 5 years that this site existed.

The second, and most important, measurement site was established in Central America. Figure 4 shows this site, which was located at Fort Clayton in the Panama Canal Zone. The Fort Clayton site was ideal in that the time zone is the same as that of Washington, D.C., and the U.S. Army Tropic Test Center is located there. Fort Clayton is at a latitude of about 9 degrees north, while the naval magazine at the Subic Bay site is at a latitude of about 14 degrees north. Thus, Fort Clayton is closer to the equator than Subic Bay. A comparison of the data from both sites indicates that very little difference in ordnance temperatures was recorded. The Fort Clayton site was established in January 1968 and returned between 66 and 72 channels of data.

As the need for more tropical measurements arose, the units were exposed at Fort Clayton, not at Subic Bay. The intention was to keep the Subic Bay measurement site small, and use it only for items that should not be placed at Fort Clayton. Some of the reasons why ordnance was exposed at Subic Bay instead of Fort Clayton were special needs of

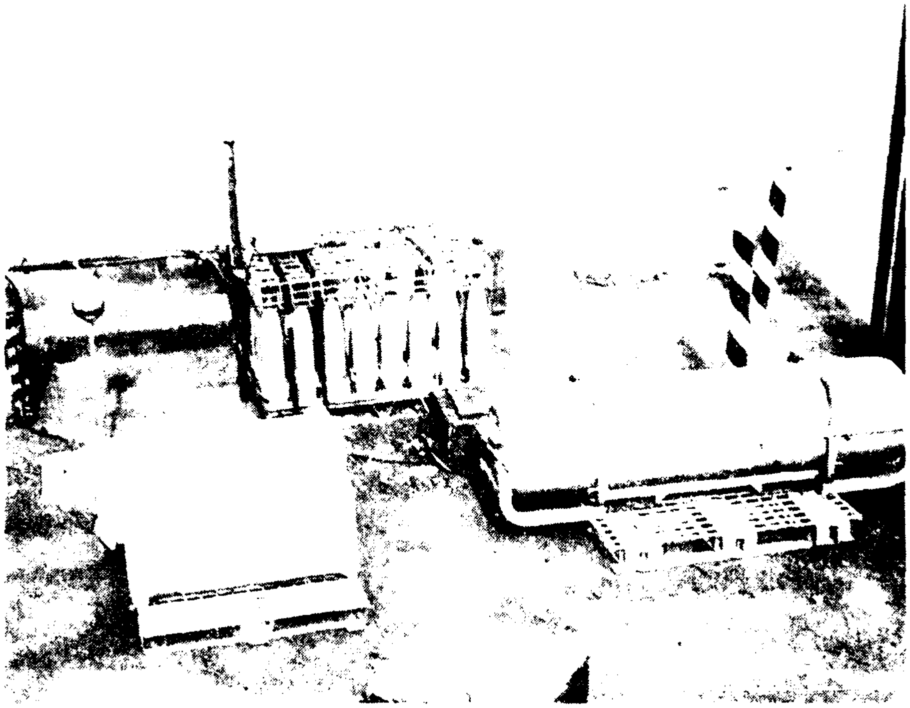

FIGURE 2. Measurement Site at Subic Bay.

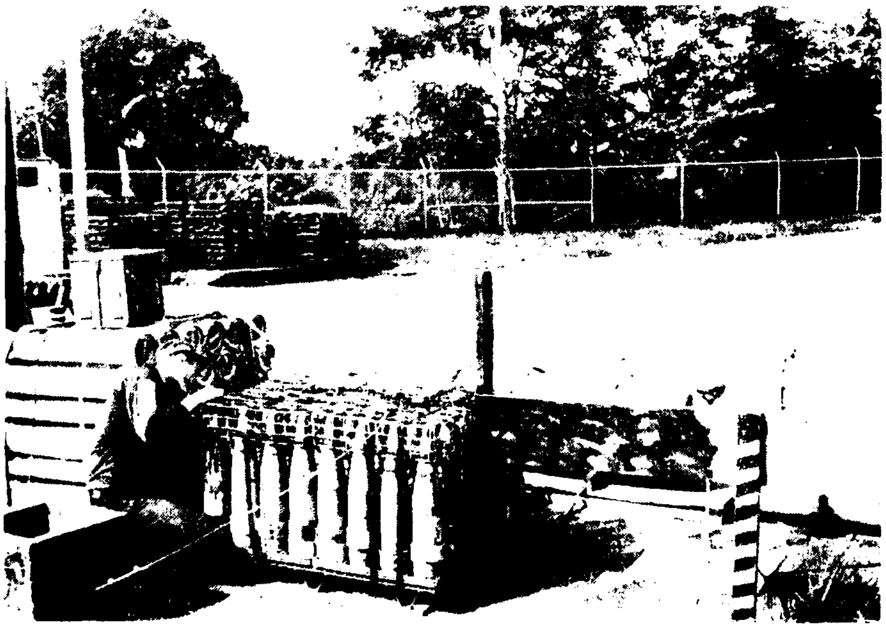

FIGURE 3. Ordnance at Subic Bay Measurement Site.

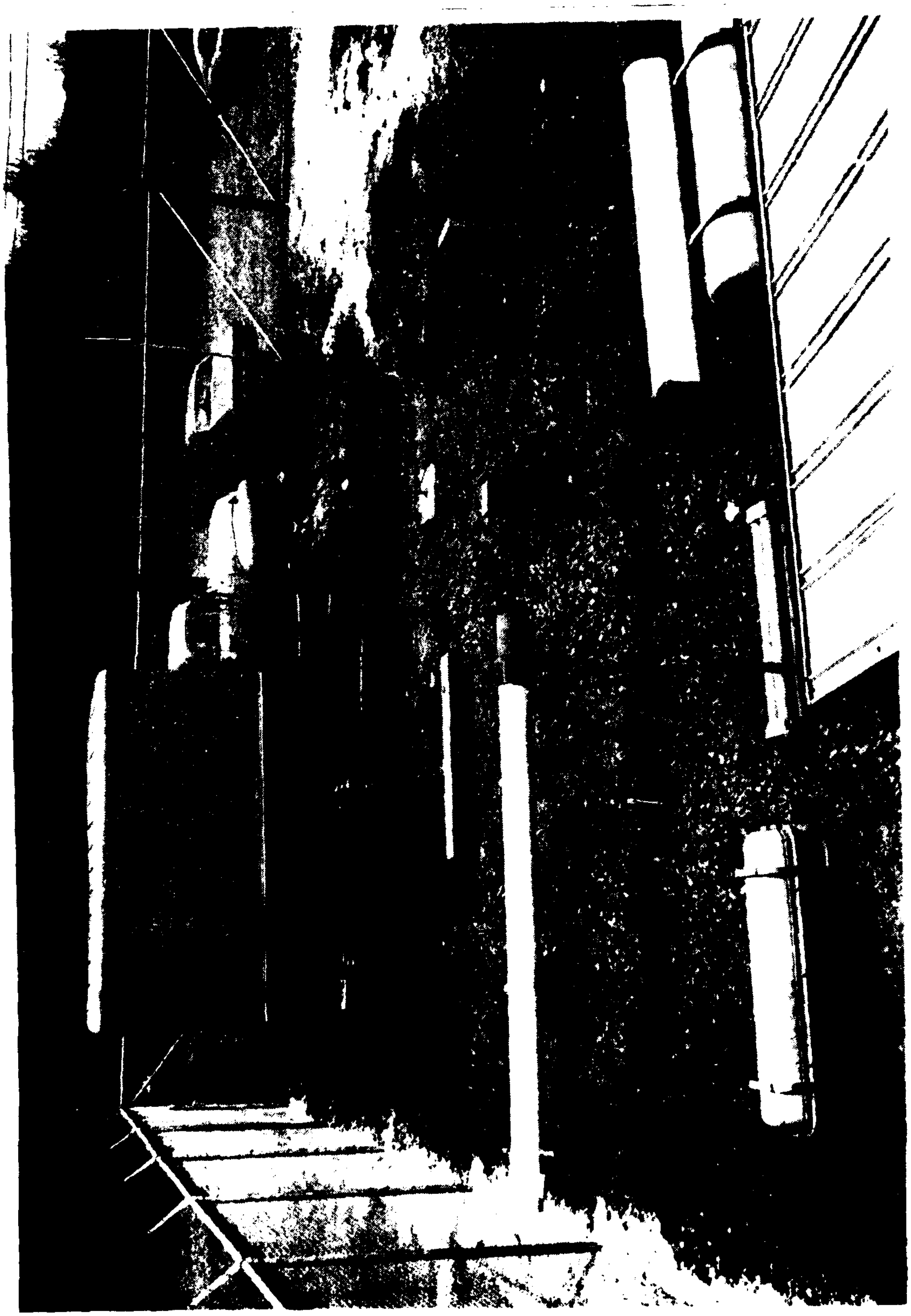

FIGURE 4. Measurement Site, Fort Clayton, Panama Canal Zone.

the project office concerned with the unit and failures that occurred in the South China Sea combat zone.

The Fort Clayton measurement site went through many changes during the time period of 1968 to 1975. Figure 4 is representative of the types and quantities of material used as measurement matrixes. About 4 million data points were returned from this site. (As with all Army Test and Evaluation Command proving grounds or test centers, complete meteorology data in pamphlet form is available. This is typically in a volume per month per station. White Sands Missile Range provides this service. Fort Clayton data are available under the code name "Gun Hill.")

Along with the U. S. Army, NWC participated in the establishment of a tropical environmental site in Thailand. No military hardware could be located at this site because of Thai-American agreements, but an NWC Thermal Standard was located at the Sukirat measurement site. This site, on the escarpment of the Korat Plateau, is representative of a typical three-tier canopy, deciduous rain forest. (This was one of the reasons for the development of the NWC Thermal Standard, which is described in References 15 through 19.) Measurements at this site were started in February 1968 and terminated in October 1970. Although meteorological data from this site are not presented in this report, they have been integrated into the tropical information presented in References 18 and 19.

Through the sponsorship of The Technical Cooperation Program (TTCP), Rocket Propulsion Working Panel (D-5), Environmental Working Group, a tropical measuring site was set up at the Joint Tropical Research Unit (JTRU), Innisfail, Queensland, Australia (Figures 5 and 6). The JTRU is a cooperative effort between Australia and the United Kingdom, both of which are members of TTCP, along with Canada and the United States. The Environmental Working Group installed 72 channels of instrumentation in conjunction with the already existing meteorological instrumentation at JTRU. The installation was completed and in operation in October 1970.

The arrangement at JTRU was that the United States (in this case, NWC, China Lake) would provide all instrumentation and connecting thermocouple extension wire. The United Kingdom provided five instrumented rocket motors, and the U.S. provided 13 instrumented rocket motors. Australia took care of recorder maintenance and repair along with data reduction. All three nations shared in the results of this endeavor. About a half-million data points were returned from this effort.

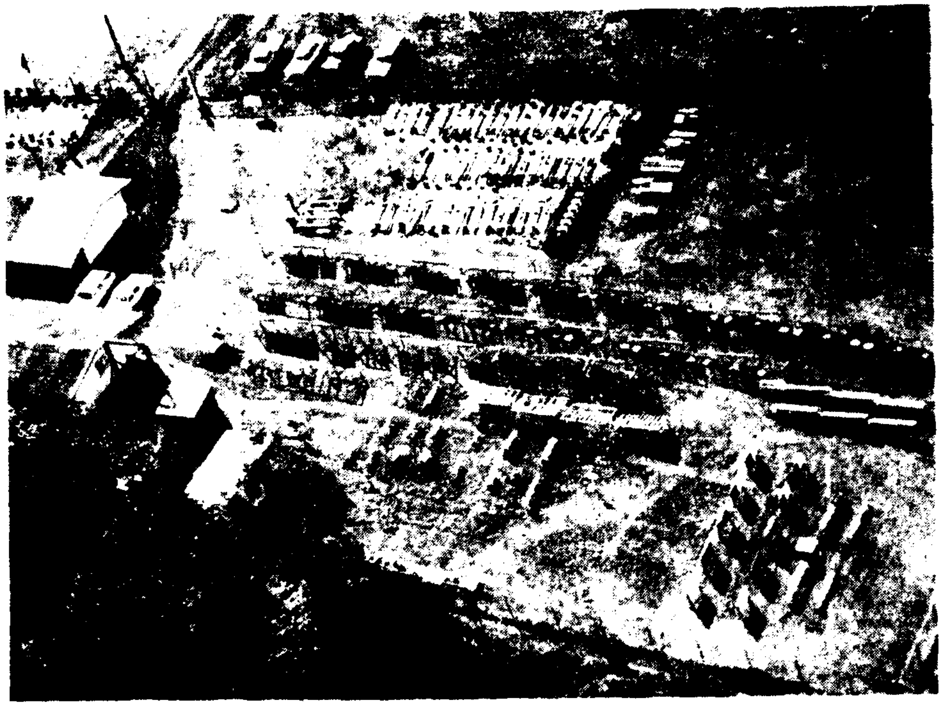

FIGURE 5. Measurement Site at Innisfail, Queensland, Australia--Overview.

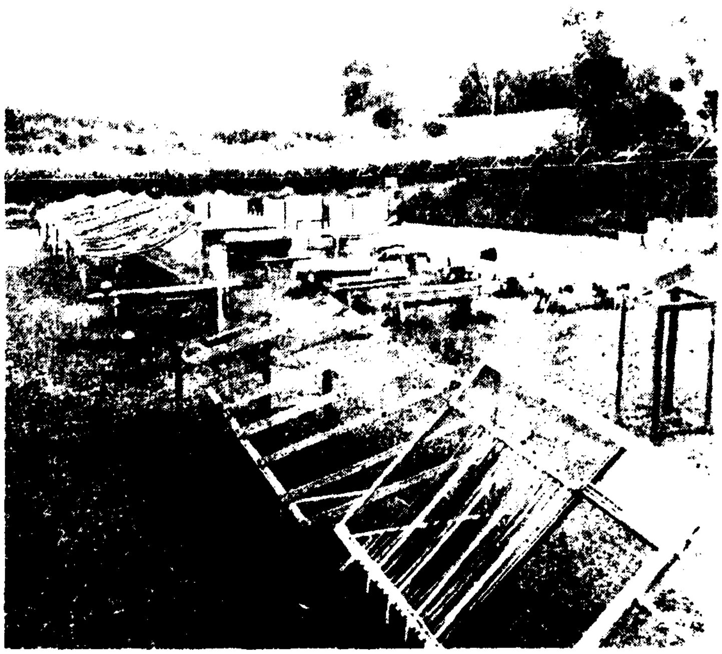

FIGURE 6. Measurement Site, Australia - Ground View.

An attempt was made to gather data on, or measure, other natural environmental functions at all of the sites. Stevenson shelter air temperature, humidity, solar radiation, wind direction and velocity are generally available from Fleet Weather Center, Naval Air Facility, Air Force, ESSA, or Army meteorological teams' records of on-site measurement. However, obtaining vast amounts of meteorological data has lost some of its significance as more extensive statistical data have been received from exposed ordnance. At one time it was seen as imperative that meteorology be judicially collected and published in this type of report. It is now realized, however, that a weapon is not designed on a site-by-site basis. Its design is predicated on a single series of "qualification tests." Therefore, it behooves the environmentalist to classify the "world," not a single site. As can be seen from the results of some of this report series, statistically there is little difference between the thermal exposure of weapons in the tropics and that in the desert. It is now possible to construct a very tentative worldwide "high temperature cumulative distribution curve" for weapon design. In this sense, the engineer is not concerned with meteorology so much as with the thermal response of the weapon in general. However, the environmental engineering specialist, or designer, should have a feel for each of the major forcing functions.

RESULTS

All the ordnance response data are based on the fact that, for tropical data, the major meteorological elements that force the ordnance to respond thermally are solar radiation, wind, air temperature, and relative humidity, and their instigators and enhancers. Since meteorological air temperature is a main thermal driving force, a plot of cumulative probability versus temperature is presented in Figure 7 for this element for an 8760-hour year.

Of significance in Figure 7 is the curve shape from the 65% (0.65) point down to the 0% point. For all following figures of cumulative probability versus temperature, the differences, both great and small, from the 65% to the 100% points should be compared with Figure 7. This domain is that of daytime solar radiation. These comparisons should provide an indication of the accuracy of meteorological data for predicting ordnance response temperatures. (However, the meteorological data are gathered by methods that were meant to be useful for agriculture, not necessarily ordnance response.)

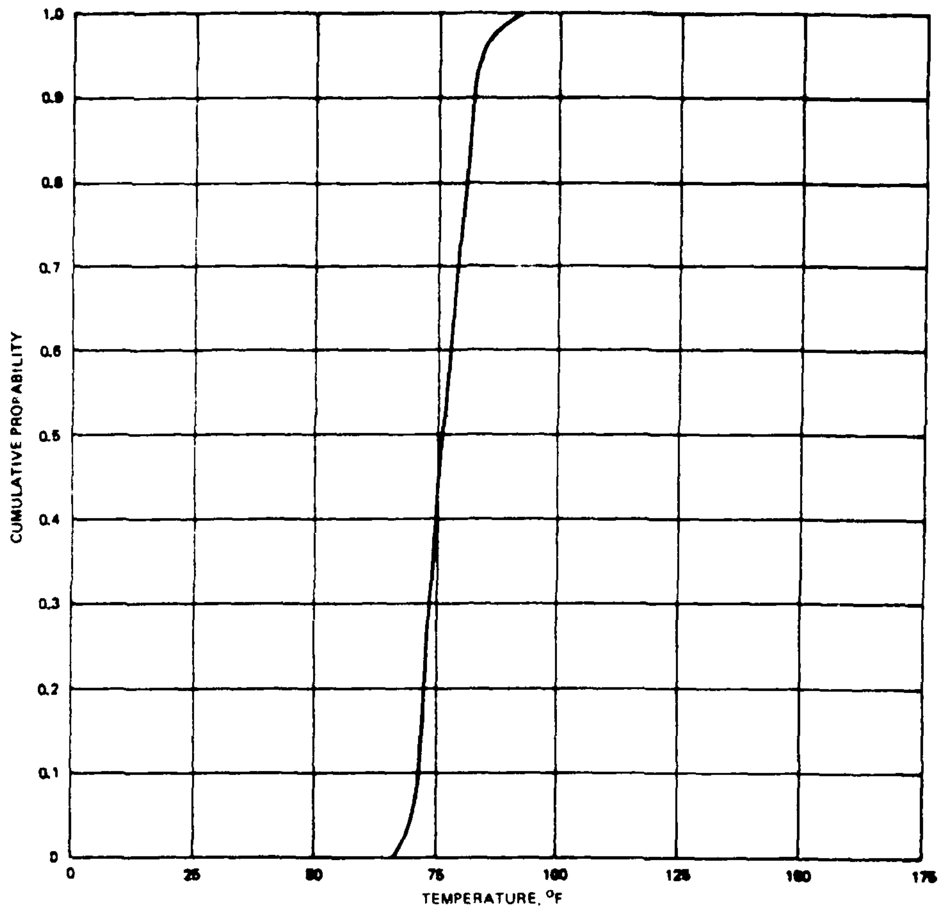

FIGURE 7. Meteorological Air Temperature, Panama, 1971-1972.

A detailed discussion as to why the cumulative probable chance of occurrence format is herein used can be found in Part 3 of NWC TP 5039, pages 8 through 12 (Reference 21). Much thought and effort over a 25-year time span went into the evolution of the presented format. It comes the closest to providing the project manager or environmental engineering specialist the necessary quantified "number."

DATA COMPOSITES

The first cumulative probability curve, Figure 8, is presented as an overlay single figure compilation of the thermal response of any material when dump (field) stored in the tropics.

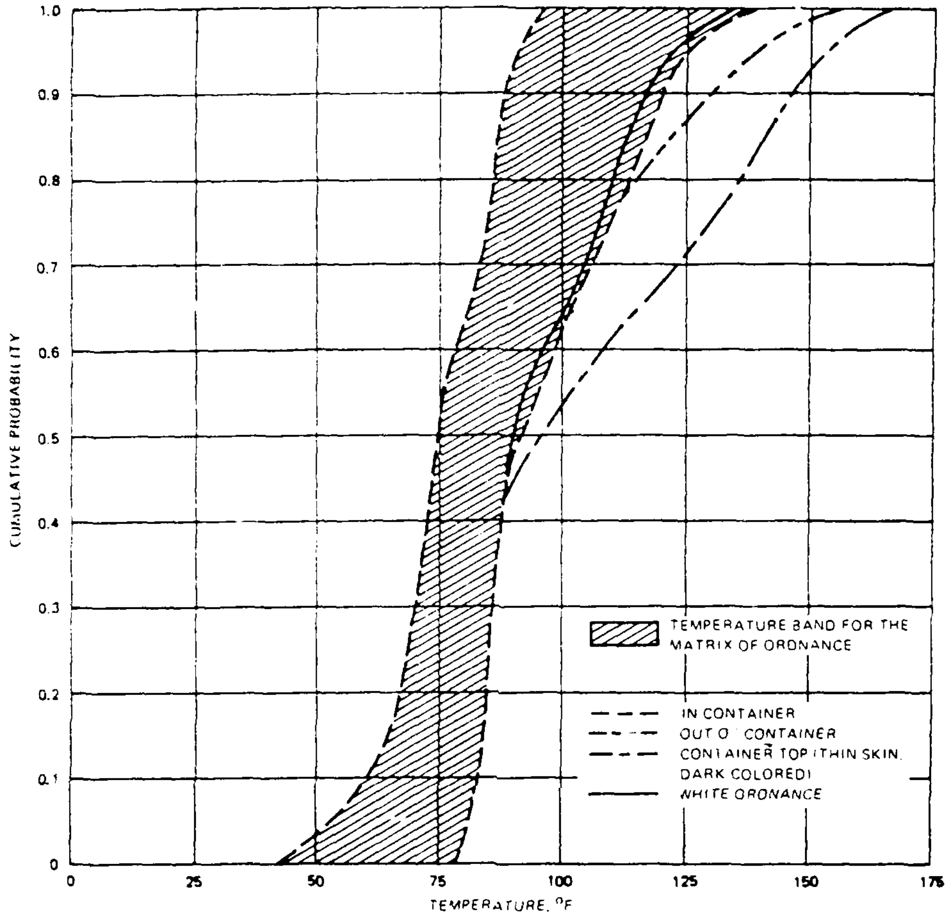

FIGURE 8. Ordnance Data; Summary of All Tropics.

Figure 8 is, in reality, a combination of the four major ordnance-type exposure situations: (1) white painted, (2) olive drab or haze gray painted, (3) thin shell in a shipping pack, or (4) small mass in a shipping pack. The envelope line in common with all material is the left-hand boundary of the cross-hatched band. Anything with a white painted exterior exposed to the sun, wind and elements, no matter what the mass, will exhibit a thermal response enveloped between the common cold boundary and the solid line. (This observation is based on 8 continuous years of hourly measurement.) The curve shape will vary as times shorter than 1 year are used since the hot end will not be as hot nor the cold end as cold. All nonwhite exterior painted stores when so exposed will respond thermally as depicted by the cross-hatched area. If, however, the shipping container is of thin shell construction, the container itself will exhibit higher thermal energy levels. It is for this special case that the separate single dashed line is included.

Depending upon where on the circumference of the thin shell shipping container the measurement is taken, the thermal response will fall between the common cold line and the hot single dashed line. Only the shipping container will experience the extreme single dashed line energy levels. The ordnance or material inside will experience only the less extreme cross-hatched thermal situation; it will not statistically experience the thermal levels of the thin skin shipping container.

One extra line on the Figure 8 composite is the double dashed line that emerges between the container top wall temperature single dashed line and the cross-hatched main body. This line is the extreme out-of-container data boundary. This boundary is for the 12 o'clock position on material not protected by a shipping container. Usually, any uncased ordnance is destined for immediate use, or it would still be inside a container.

The remainder of this report contains figures derived from the 5 million data points obtained at the three worldwide locations for tropic dump storage that contributed to this composite envelope. Figure 8 is, in essence, nothing more than a composite overlay of the remaining figures and represents a total envelope of this representative sampling of field measurements. Thermal response data were obtained for the following ordnance categories (an example of the digital data from which figures like these were derived was given in Reference 23):

1. Missile out of shipping container
2. Missile in shipping container
3. Bombs
4. Fuzes
5. Naval gun projectiles
6. Small arms ammunition

Figures 9 through 11 show breakdowns of Figure 8 into the three major separate storage dump composites.

Figure 9, the composite for Panama, shows that ordnance not in shipping containers exhibits a cooler domain than similar ordnance that is cased. This is attributable to night sky radiation. Though this phenomenon was not as pronounced as in desert measurements, finding it in the humid tropics was a surprise. Since the temperature band (cross-hatched area of Figure 9) is intended for design criteria use, and the tropics are "hot," the in-container data are cross-hatched, and the out-of-container data envelopes are just presented for information.

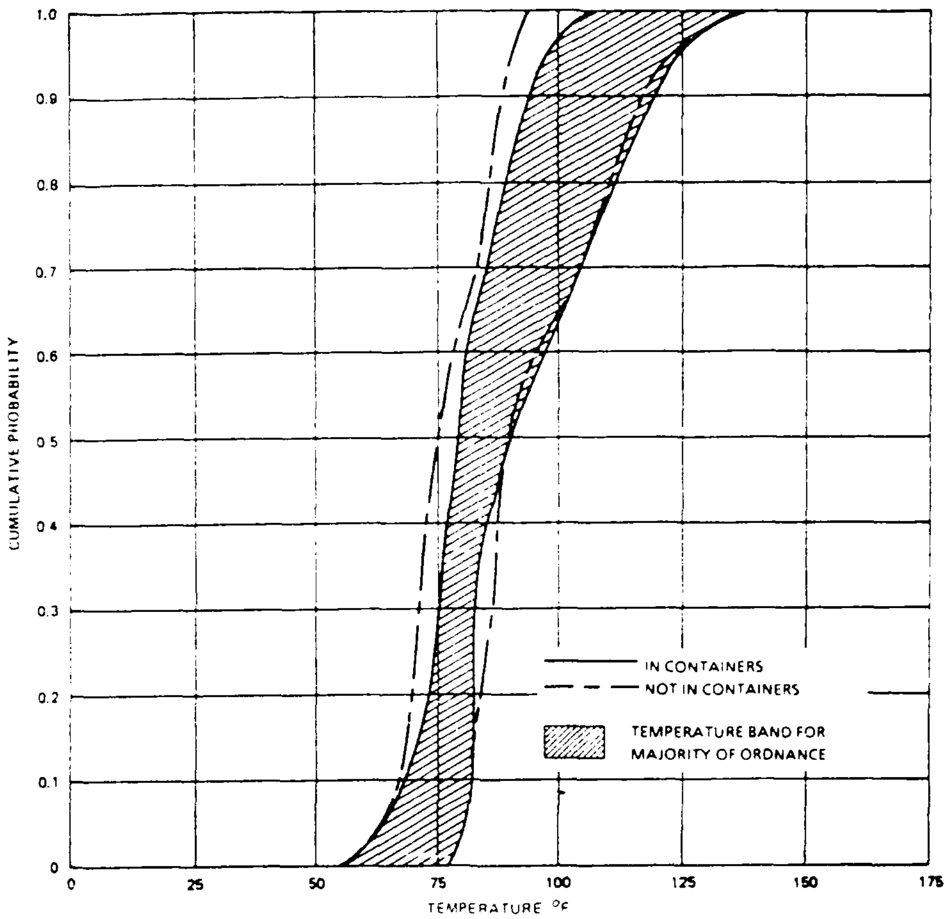

FIGURE 9. Ordnance Data; Panama.

In Figure 10 there is no such ambiguity. No reported ordnance data from Subic Bay are presented for the out-of-container situation, except for a gun projectile fuze. Therefore, Figure 10 is a display of in-container data only.

Figure 11 shows the composite data from the Australian tropics. The data from the southern hemisphere tropics take the same cumulative probability display shapes as those from northern hemisphere tropics. The reason for the more extreme hot temperature domain is that the monsoon shift really provides data from two meteorological data bases. When the wind is off the Coral Sea and Great Barrier Reef, the data look very much like data from Panama or Subic Bay. However, during monsoon season, the wind comes down off the Atherton Tablelands, which is really inland desert. Therefore, the hot domain of Figure 11 resembles a desert environment (Reference 21).

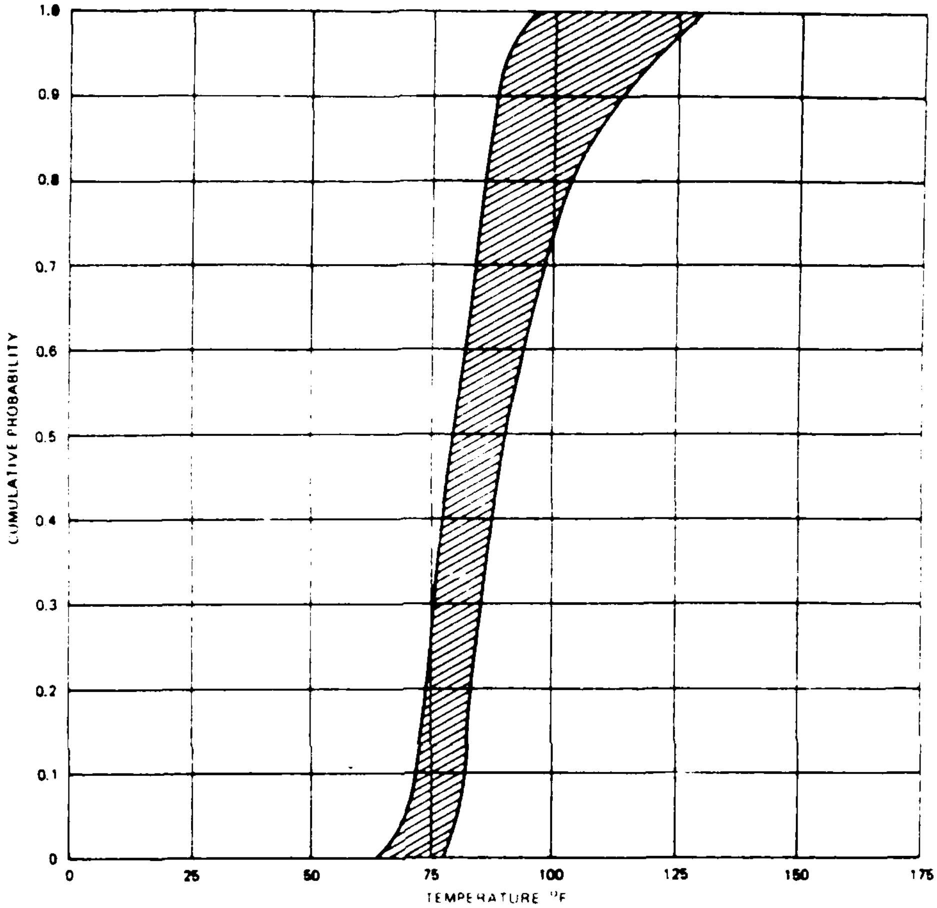

FIGURE 10. Ordnance Data (in Containers); Subic Bay.

DATA ON INDIVIDUAL TYPES OF ORDNANCE

The remainder of the data presented herein are for specific ordnance. Data for projecting probable thermal response guidelines for a new Thermal Standard can be found in Parts 1 and 2 of NWC TP 4834 (References 15 and 16).

In the more normal dump or ready-use exposed storage situation, the missile is kept inside some type of shipping container or combination container and launcher. In general, in-container dump-stored missiles are usually in a stack of like items, not separately segregated into one-unit lots. The data herein presented are for one-unit lots and, therefore, extreme in the real world overall use

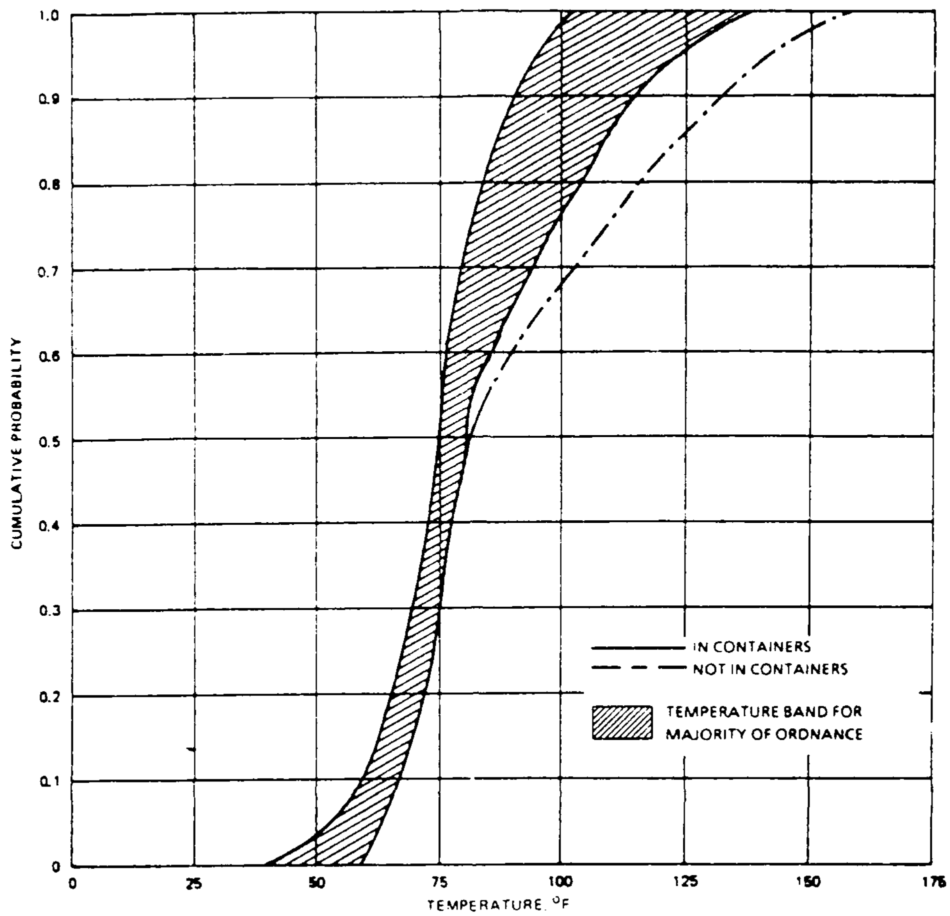

FIGURE 11. Ordnance Data; Australia.

context. (Appendix B provides an idea of how extreme the single round exposure probably is.)

The data for Panama are presented first, followed by those for Subic Bay and then those for Innisfail Australia. The order was chosen to reflect the amount of usable data returned during the program as a whole. With about 4 million data points, Panama was by far the most productive of the three sites herein reported.

Panama Measurement Site

Figure 12 is representative of the thermal response of small rockets in a "dense pack." The 2.75-inch folding fin air rocket (FFAR) has been in the U.S. arsenal since the beginning of the Korean War.

It, or a product improvement version, will probably be in use for another 35 or 40 years. Though Figure 12 is somewhat cluttered, a single "data line" shape represents the many positions measured in the 2.75-inch FFAR four-pack. As can be seen, even though the unit is small, and externally painted a haze gray color, the thermal response band is quite narrow. Even the top (12 o'clock position) of the top two container tubes did not exhibit temperatures above 135°F for many hours. The majority of the time, 75%, no part of the unit exceeded a temperature greater than 100°F, including the thin-walled gray shipping container itself.

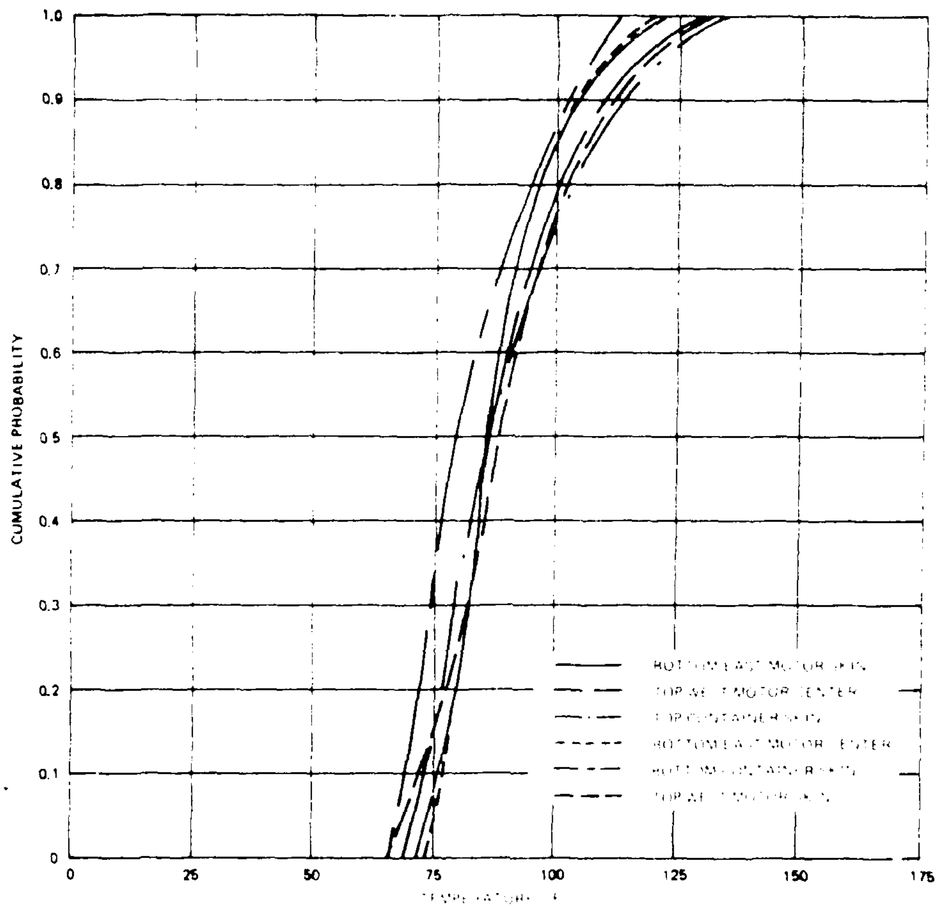

FIGURE 12. Four 2.75-Inch Rockets in Gray Shipping Containers/Launchers; Panama, 1968-1975.

Figure 13 is the thermal response of 5-inch-diameter Zuni ballistic rockets, stored in a four-unit white cylindrical shipping container/launcher, (LAU-10 launcher). The white color (which didn't really stay white over the years of exposure) is highly effective in keeping rocket motor temperature down. About 93% of the time, the complete unit exhibited temperatures of 100°F or less. If possible, shipping containers and missile surfaces should be painted white for lower thermal responses. As a rule, white paint should provide a 25°F maximum temperature drop for design purposes. This also holds true for hot desert exposures, (Reference 21, Figure 5).

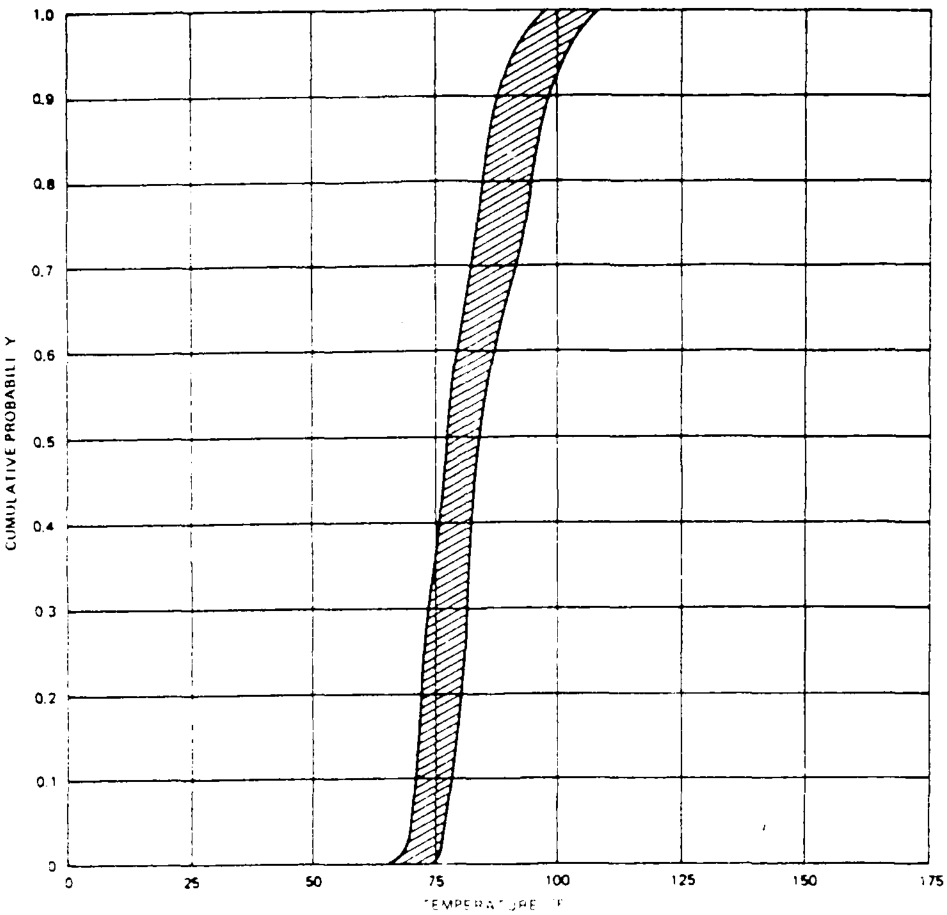

FIGURE 13. 5-Inch Zuni Rocket in White Launcher Motor Skin; Panama, 1968-1974.

Figure 14 is the thermal display for an all-up Sparrow 8-inch-diameter air-to-air missile set on 3-foot-high aluminum, minimum-contact stands. The missile was painted white and initially was quite shiny. However, as the years went by, the black fungal growth so prevalent in all tropics at first dulled and then roughened and darkened the "white" surface. Even so, only the low mass, low thermal conductivity radome reported temperatures much above 125°F. The center of the rocket motor and the east, west, and bottom quadrants of the missile surface skin reported temperatures of 110°F or less.

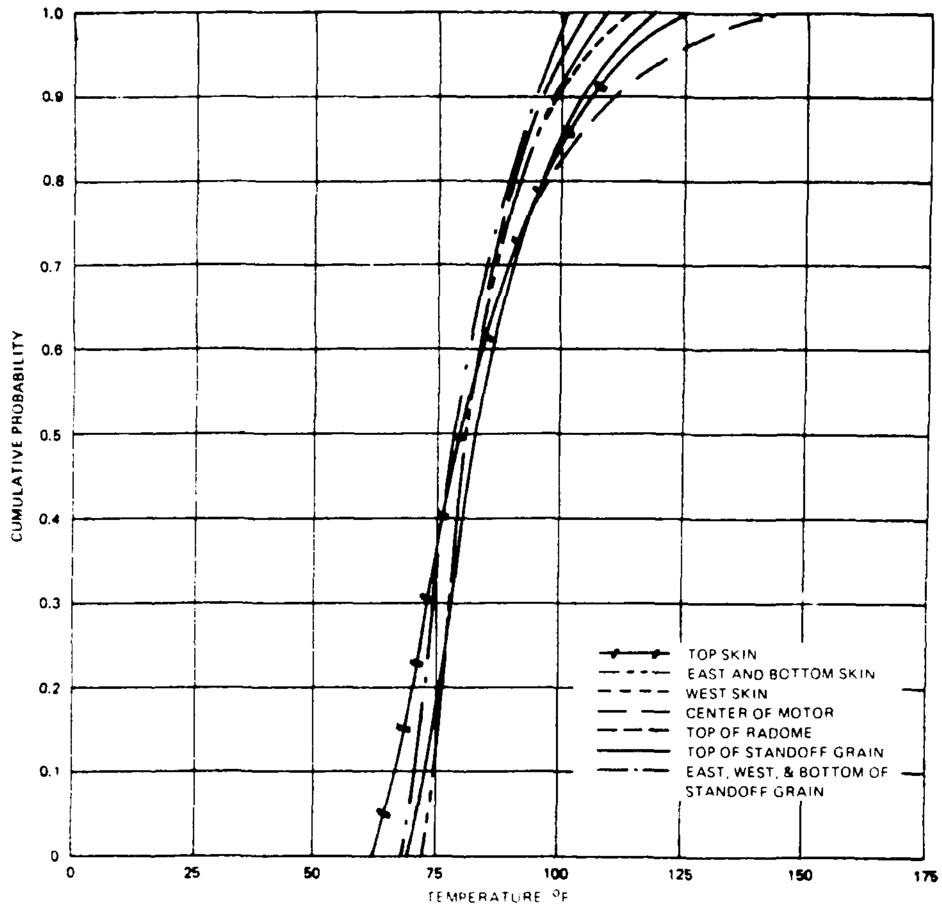

FIGURE 14. Complete Sparrow Missile, Out of Shipping Container on 3-Foot-High Horizontal Stand; Panama, 1969-1974.

Each of these individual temperature response plots in particular and all data plots herein reported in general indicate that at no time is a unit "soaked" at a single temperature value in the natural exposure. This is especially true for the extreme temperature excursions. There is always a thermal gradient from the hot surface to the cold surface. It is suggested that this basic fact be considered during the design of new missiles, ordnance, and material. In reality, the only situations in which the extreme temperature domain is a gradientless soak are during arctic cold or during an "environmental conditioning chamber (oven) test."

The companion data for the 8-inch Sparrow rocket motor in a haze gray, steel, thin-wall (16 gage) cylindrical shipping container are shown in Figure 15. Because data from the 8-inch diameter measurement matrix are universally used, Figure 15 is more detailed than most other data displays in this report. Only two thermocouples worth of data, over an 8-year time span, are presented. The spread of temperature for the 12 o'clock top-of-the-motor-skin position is about 17°F at the 90% line of the display. At the 100% line the spread is the greatest at about 25°F. This is to be expected, as events that may occur at the 100% line are not very probable. The band representing the thermal response of the center of the rocket motor grain is much cooler than the band representing the container surface from the 60% domain (0.6) on up to 100% (1.0).

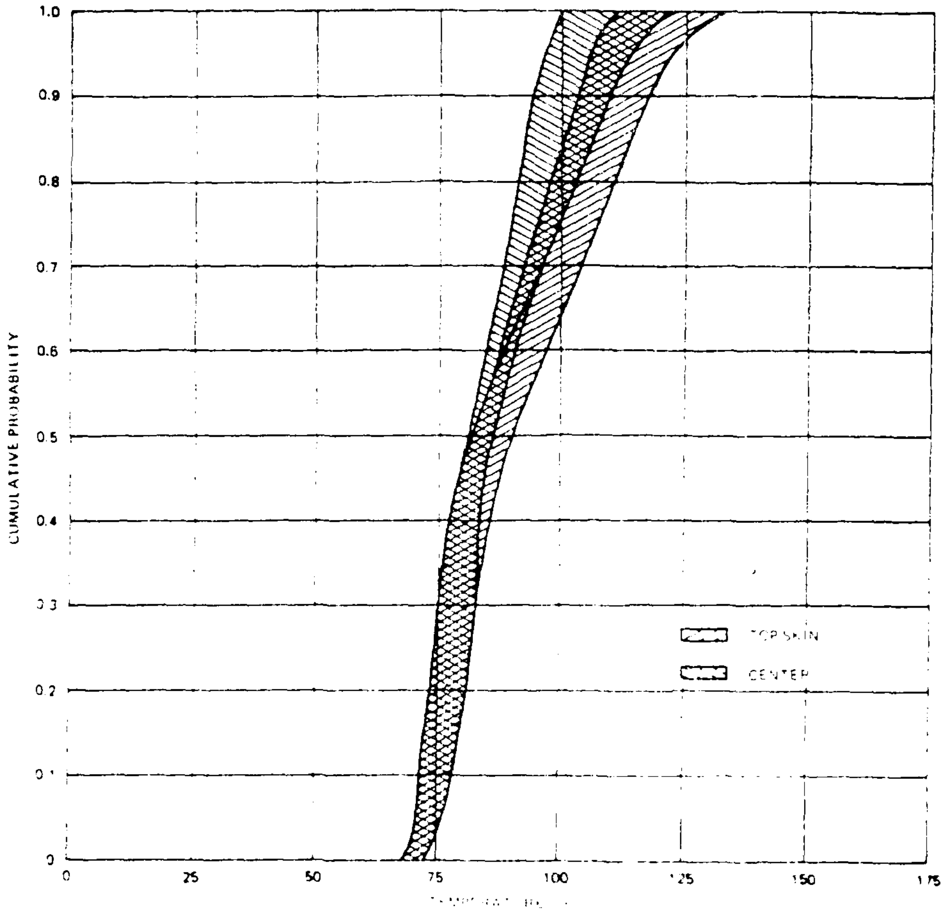

FIGURE 15. Sparrow: 8-Inch Rocket Motor in Container; Panama, 1968-1975.

On the basis of data such as these, if a designer is forced to specify a single, gradientless, soak temperature (or bulk temperature) for the thermal design goal in the development specification, the "center of the rocket motor" band could provide guidance. Unpublished work by R. Ulrich of Brigham Young University has shown that thermal data derived from rocket motor exposures is also extremely representative of warhead, target detecting device, and guidance and control sections of missiles. The baseline reason is that the thermal densities are about the same for most sections of a sophisticated missile, except for the skin-mounted antennas and low mass radome. Therefore, the thermal criteria of a complete missile may be based on data such as those shown in Figure 15.

An example of how to use Figure 15 for design criteria might be: (1) Assume a design risk. For example, assume that the program requires an 85% reliability design goal for the entire unit. Then assume that the thermal design goal for any component of the unit should be, for example, 95%. (The numbers used in this example are arbitrary; however, they are based on some experience in the field. Do not use these numbers for your weapon, as you will have a different "reliability budget.") (2) Look at the 0.95 line in Figure 15. The center-of-missile band seems to span about 95 to 115°F. The skin-of-container band encompasses the 110 to about 120°F region. Consequently, the "design number" should lie between 95 and 120°F. (3) Select a temperature value for the product design specification, based on knowledge of how propellants and electronics react to temperature and on engineering judgment. There is a band of temperature between about 0 to -10°F and 120 to 130°F at which the performance characteristics are about constant. Below 0 to -10°F, the performance characteristics rapidly drop off, and above 120 to 130°F, they go wild. (The author advocates 130°F for the product design specification if tropical dump storage is to be the only event in the factory-to-use sequence. Reference 1 and Appendix A contain more ideas on the factory-to-use sequence.) (4) Assuming that the 130°F value has been selected, quantify this value. At about 0.995, it intersects the lead envelope line of the shipping container band. The statement then can be made that "based on the shipping container maximum temperature line, the probable chance of occurrence of 130°F is 99.5%." (That is 99.5% of the time, the temperature of the top of the container in which the item is stored will be 130°F OR LESS).

On the basis of Figure 15, the center of the missile will never reach 130°F. Now, if the program manager must change the 130°F design goal to, say, 125 or 120°F for reasons of reliability, cost, performance, or development time, the "risk" of these waiver temperature values can be read from Figure 15; i.e. about 96% and 95%

for the shipping container "hot line" or 100% for the center of the rocket motor "hot line."

Figure 16 is the equivalent of Figure 15 for an 11-inch-diameter rocket motor. Data from three thermocouples are displayed in this figure. The top end data are more extreme for the larger diameter missile than for the smaller diameter missile of Figure 15. Both missiles are in cylindrical shipping containers of like geometry. The larger missile of Figure 16 is in a container with a diameter of about 2 feet, while the smaller missile of Figure 15 is in a container with a diameter of only about 16 inches.

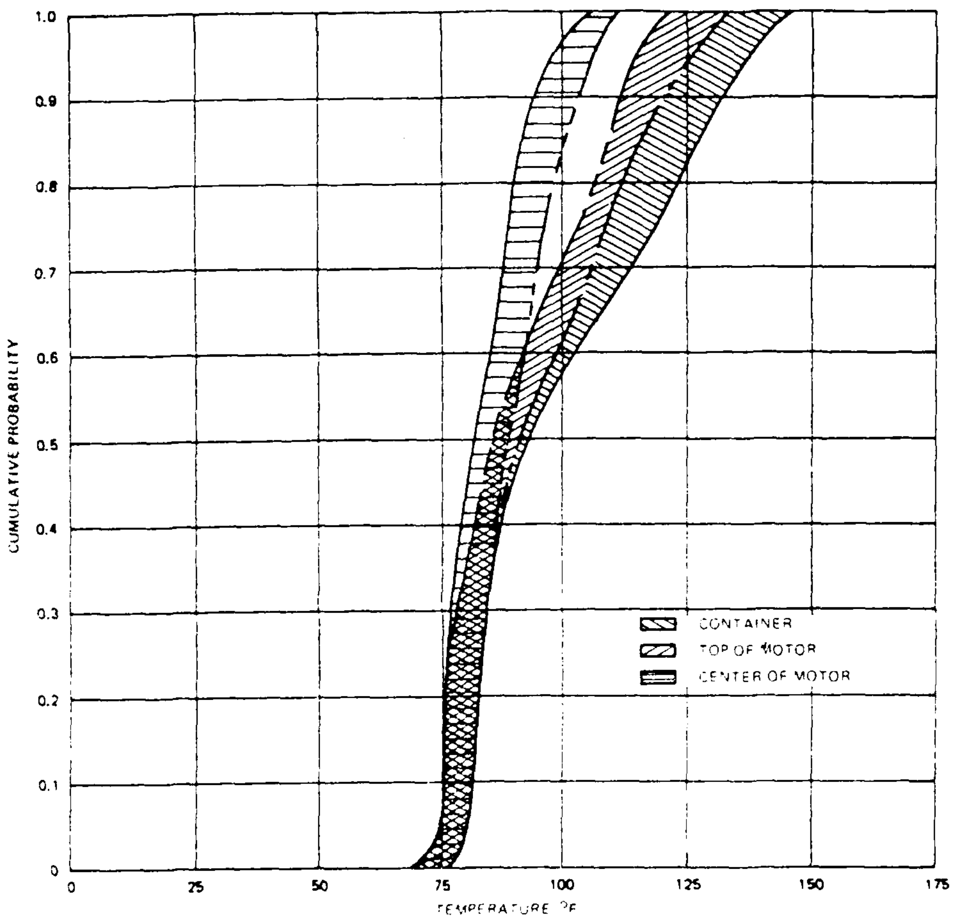

FIGURE 16. 12-Inch-Diameter Rocket (ASROC) Motor; Panama, 1968-1975.

All the containers, motors, and missiles reported in this document were placed so that the major axis of "rotation" was north-south oriented. This exposes the unit to the maximum normal solar radiation during the day if the unit or assembly is cylindrical. Even if the container is rectangular this orientation will be conducive to the most extreme irradiation, though true normal insolation is only possible three times a day: morning, solar noon, and sundown. At all other times the heat available to the surface of the rectangular container would be less than would be available if the exposure were at right angles to the sun. These data indicate that a "square" container will protect a unit from solar radiation better than a cylindrical one (even more so if painted white).

The reason the container of Figure 16 is "hotter" than that of Figure 15 is that there is a wider band of near normal exposure at all sun times because of the larger diameter. The normality of exposure in both cases is the east "side" at sunup. This progresses throughout the day to normality at the west "side" at sundown. In such a circumstance the thermal gradient through the unit changes a nominal 180°F each day. At the solar noon, maximum insolation period of the day, any container will give the enclosed material the most fierce gradient of the day. This is caused by the sun heating the top of the container more than any other part. Also, hot air rises in a free convection mode. Inside the container, the top wall heats up the air underneath it. The hot air cannot go anywhere, so by free convection of the stagnant air, and radiation from the inner wall of the container top, heat is transferred down into the enclosed material. These heat transfer processes are not very efficient, and the time of maximum heat is only about 3 hours on the most extreme day, so the bottom of the unit is not heated much. Therefore, an extreme thermal gradient situation develops.

The data displayed in Figures 17 through 19 indicate the extent to which steel conducts heat in the directional heating conditions of exposure to solar radiation and show how much shielding the ordnance itself gives the units under and alongside it. These figures show the thermal responses of 250-pound bombs palletized in a two-row eight pack. They are painted olive drab in color and probably have an absorptivity of about 0.98.

The bomb shown in Figure 17 (west side) shows higher temperature maximums that does the Figure 18 bomb (top or east sides). As would be expected, the Figure 19 sheltered top of bottom row stayed quite "cool" during the maximum reported temperatures. There is about a 25°F difference between the Figures 17 and 19 maximum reported exposure. It is on the basis of observations such as these that Appendix A is presented.

Figures 20 and 21 show the thermal responses of larger aerial bombs, which are geometrically the same as the bombs covered by Figures 17 through 19 but larger (500 and 1000 pounds). They are presented here for the sake of completeness.

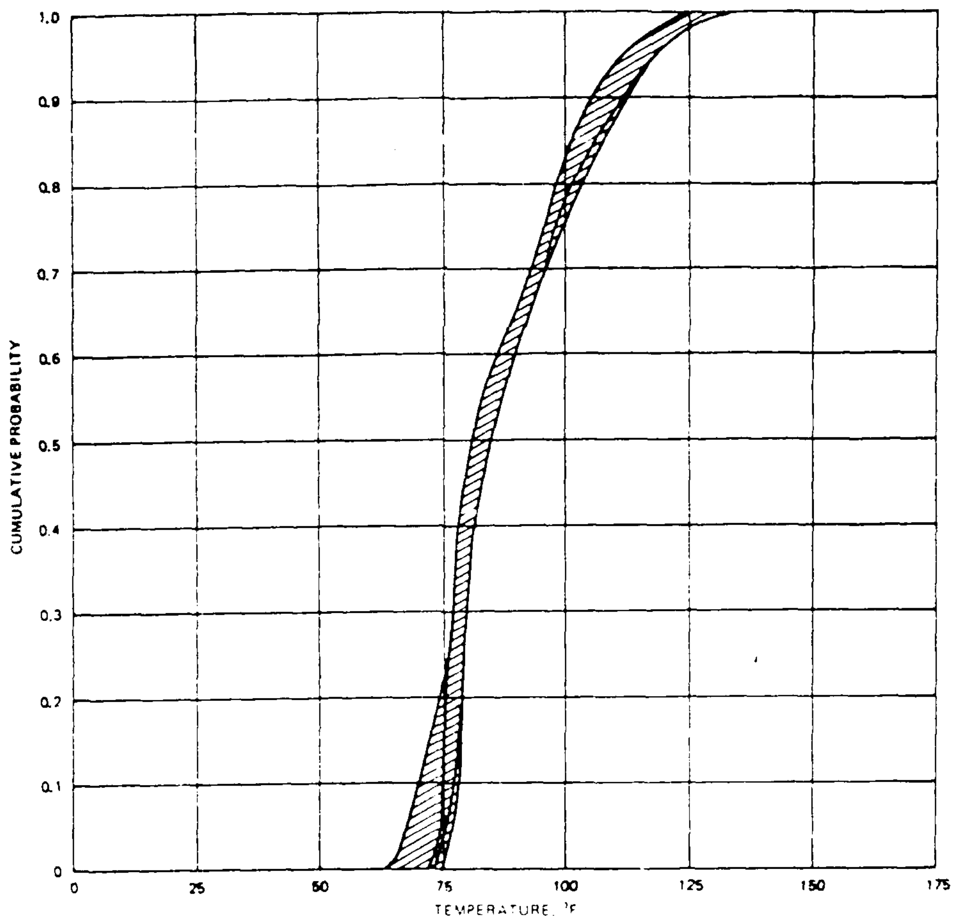

FIGURE 17. Mk 81 250-Pound Low-Drag Bomb - West Side; Panama, 1968-1975.

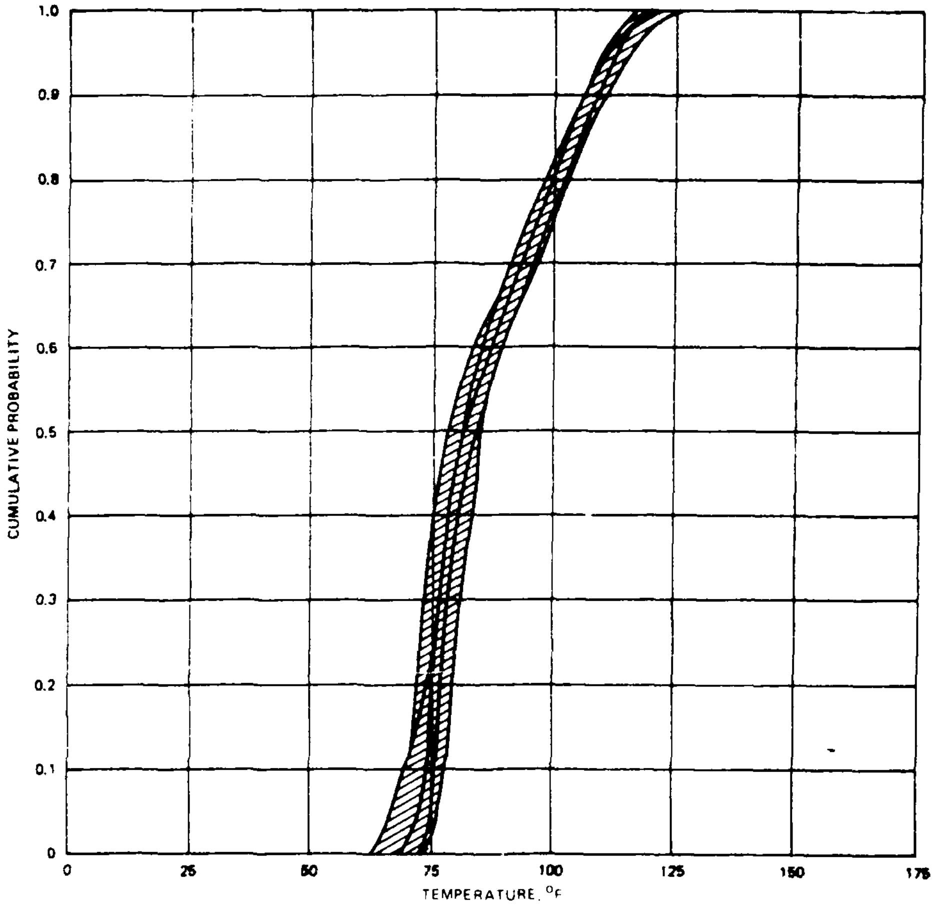

FIGURE 18. Mk 81 250-Pound Low-Drag Bomb–Top and East Sides; Panama, 1968-1975.

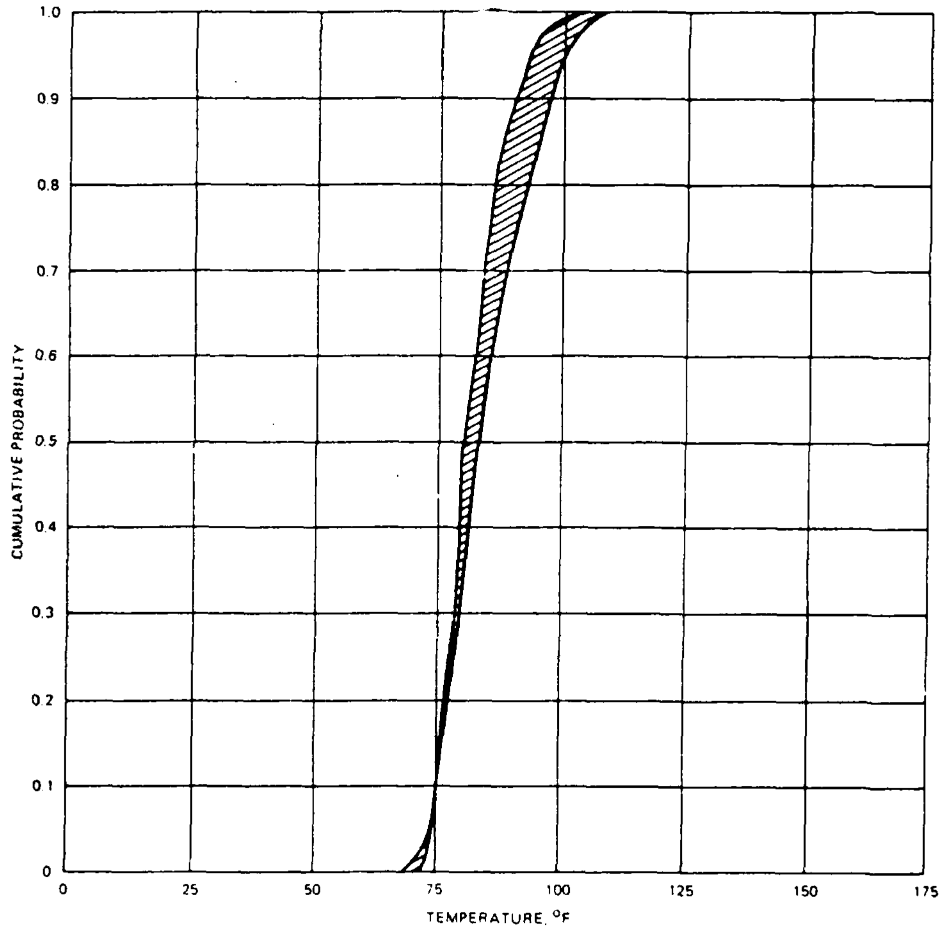

FIGURE 19. Mk 81 250-Pound Low-Drag Bomb–Top of Bottom Row; Panama, 1968-1969.

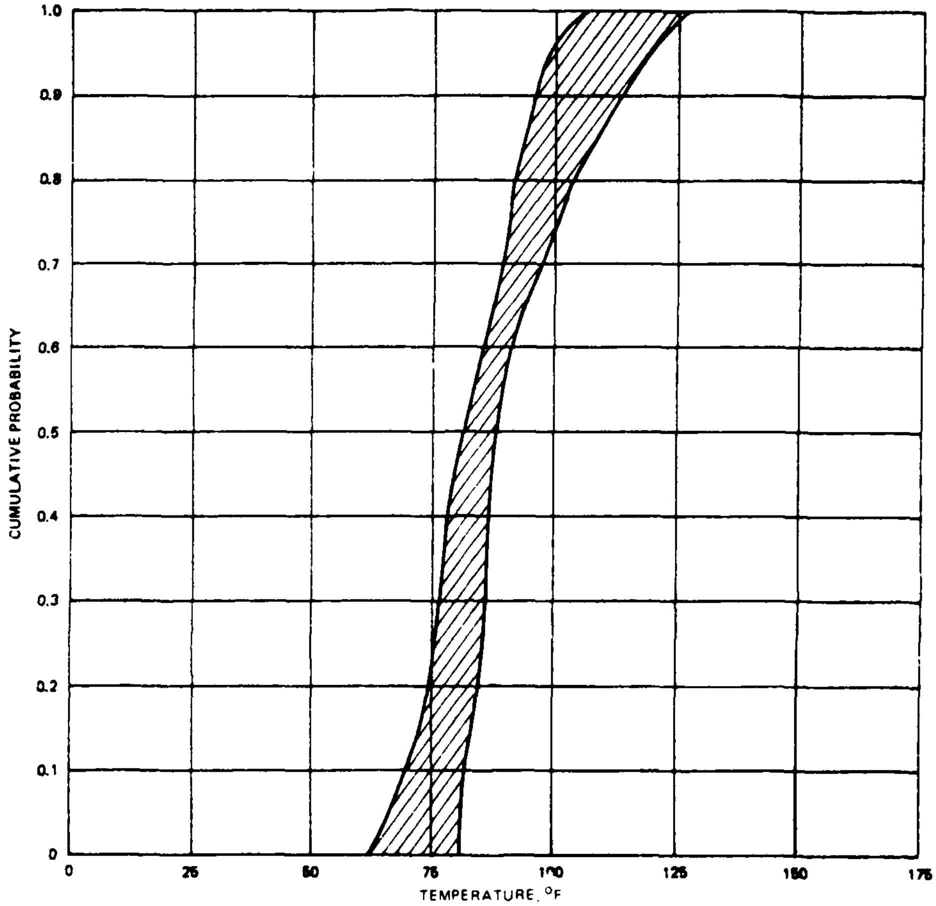

FIGURE 20. Mk 82 500-Pound Low-Drag Bomb; Panama, 1968-1975.

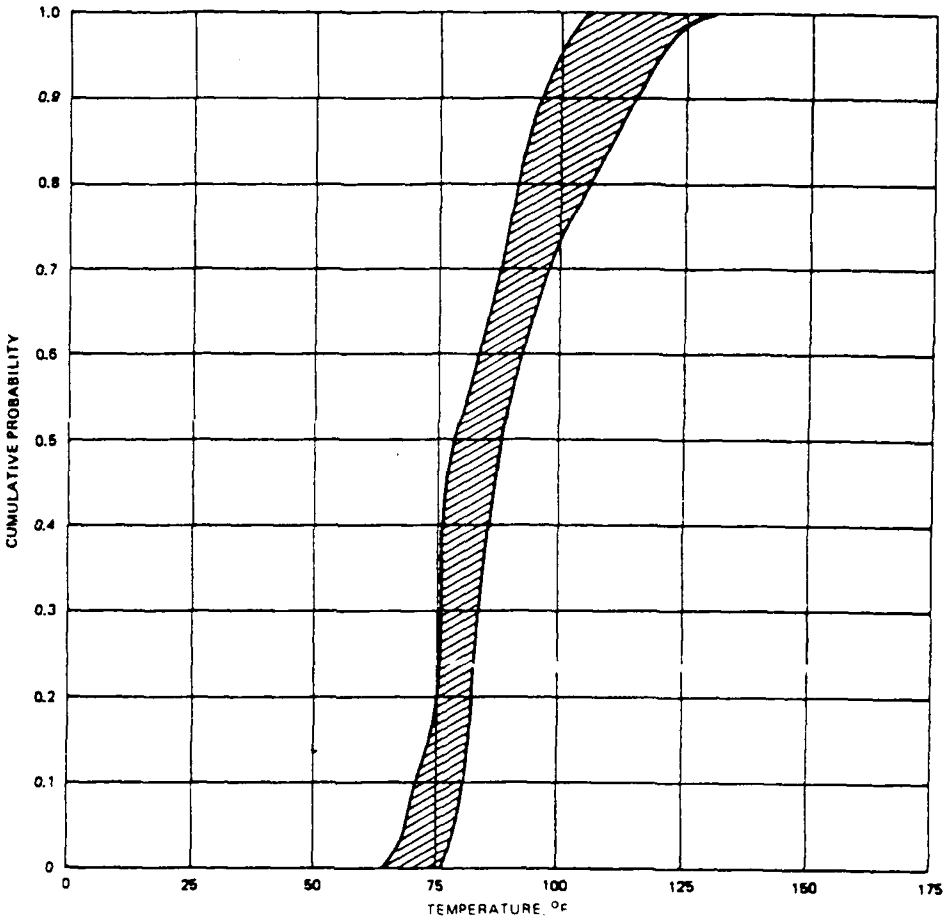

FIGURE 21. Mk 83 1000-Pound Low-Drag Bomb;, Panama, 1968-1975.

The next series, on gun projectiles, is representative of a range of materiel exposures. Gun projectiles are treated as if they are relatively impervious to the environment. They are palletized on wire mesh pallets with a wire top to keep them from falling or scattering. This mode of shipment gives the projectile no thermal protection. However, the projectiles are palletized in an upright position so that the ogive is pointing toward the sky. Hence, the smallest cross section is exhibited to the "solar noon" sun. Since the maximum insolation is at solar noon, the projectiles absorb less radiated heat at solar noon than they would if placed in any other position.

Figure 22 illustrates the exposure of the 105-mm howitzer projectile. This figure can be viewed as an extreme for tropical use, since the 105-mm projectiles used in this measurement sequence were never filled with explosive or plaster. Therefore, the thermal mass was about 60% of that of an "issue" round. Also, these rounds reach higher maximum temperatures for a given exposure than would the live counterparts. Even so, Figure 22 shows a peak at about 130°F.

Figure 23 shows data for World War II 120-mm antiaircraft rounds that were factory filled and plugged. (This projectile resembles the 105-mm projectile, although it is larger.) The figure indicates a maximum 7+ year temperature of less than 130°F.

Figure 24 shows data on the bottom surfaces of the 120-mm projectile. The maximum temperatures are lower than those reported in Figure 23 for the ogive.

The final figure in the projectile series depicts the thermal history of the 6-inch naval projectile. This also was a pallet of empty units. Even so, the temperatures at any given point, as shown in Figure 25, are moderate. One conclusion that can be drawn from all the exposed and packed ordnance is that never did it come close to the design value of 165°F.

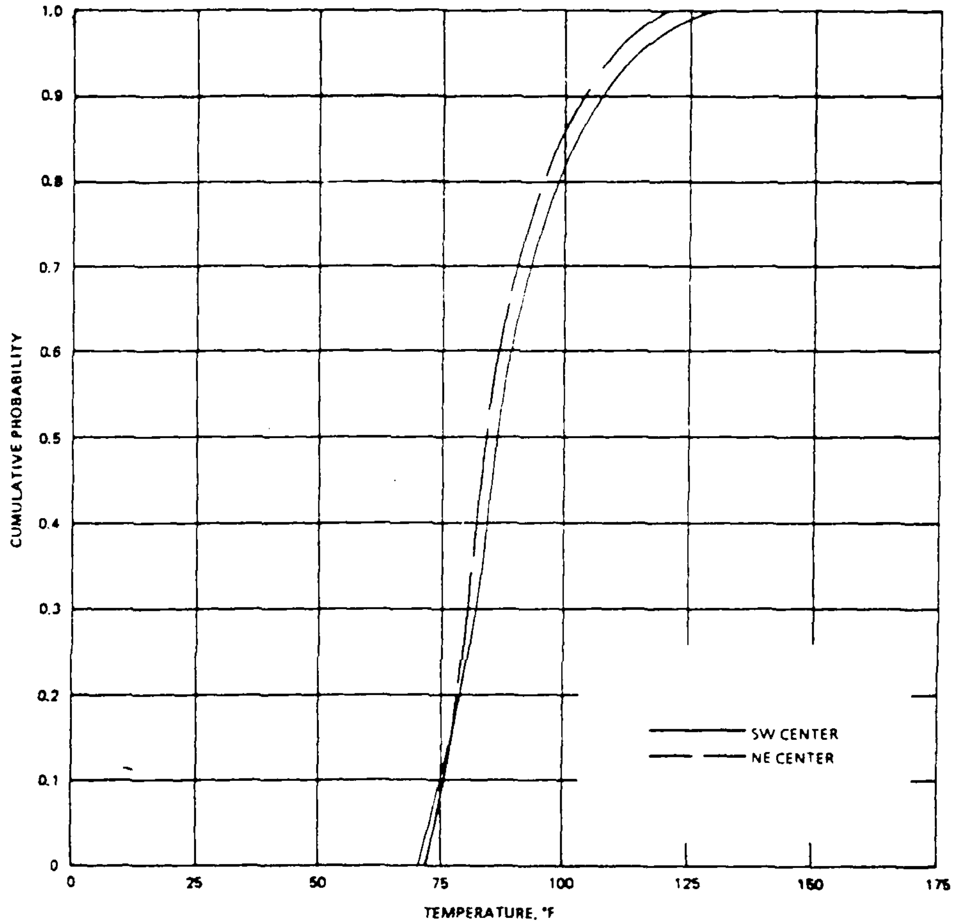

FIGURE 22. 105-mm Projectile; Panama, 1968-1975.

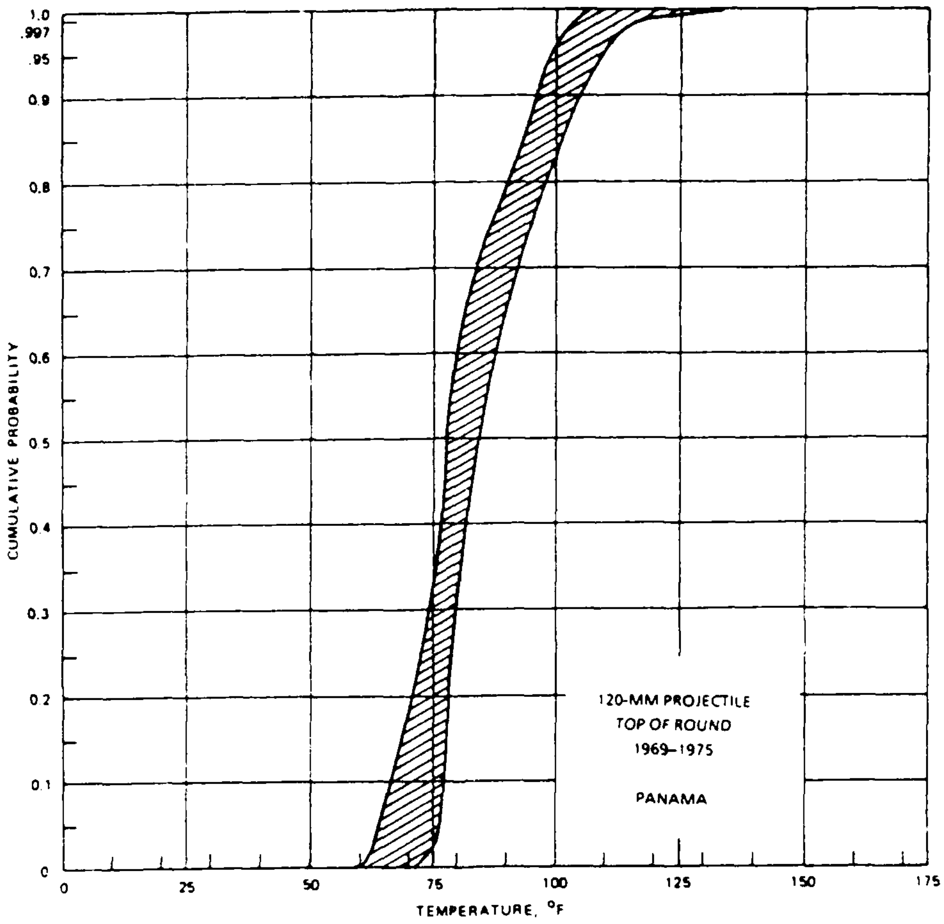

FIGURE 23. 120-mm Projectile, Top of Round; Panama, 1968-1975.

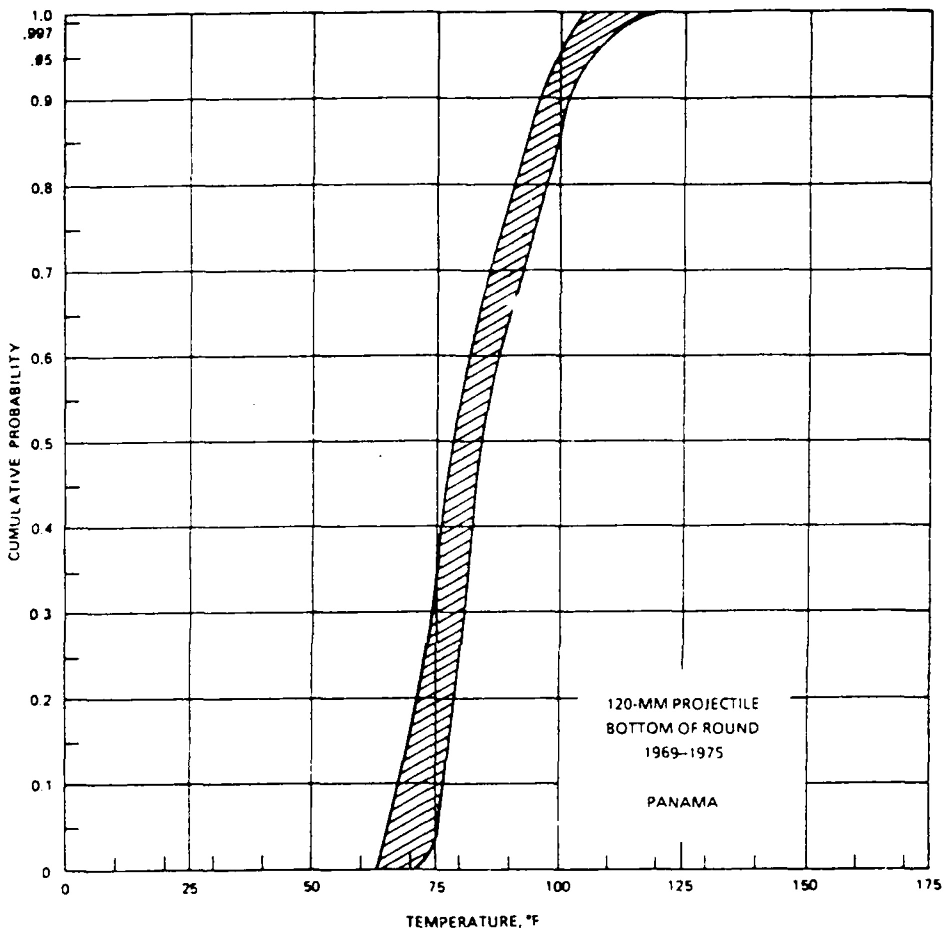

FIGURE 24. 120-mm Projectile, Bottom of Round; Panama, 1968-1975.

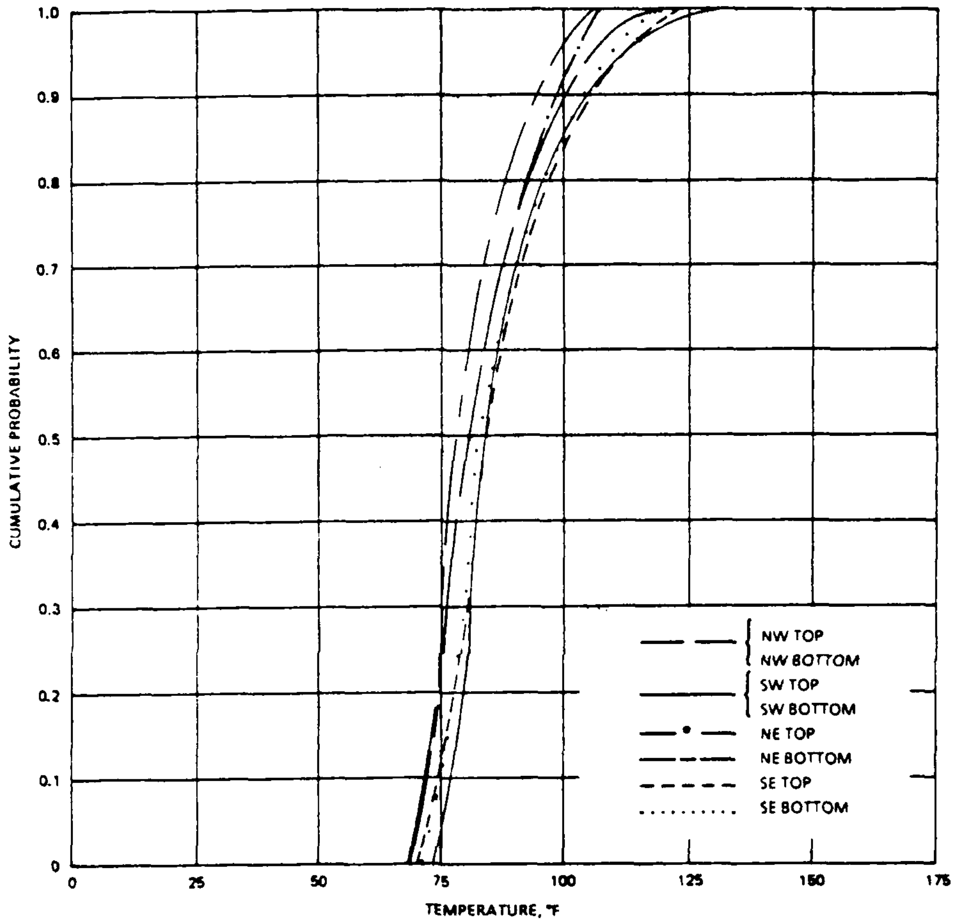

FIGURE 25. 6-inch Projectile; Panama, 1968-1975.

In response to a request from a development project, the next items were added to the exposure series. Bomb fuzes were placed in a regulation 50-caliber metal ammunition box. They were then placed on top of a pallet of ordnance for complete exposure to the sun. As seen in Figure 26, the top fuze in the olive drab can recorded a maximum temperature of nearly 140°F. The recorded temperatures of the remaining fuzes were about 10°F cooler during the one hot day in more than 5 years of exposure. These fuzes were all-up rounds except for the booster explosive.

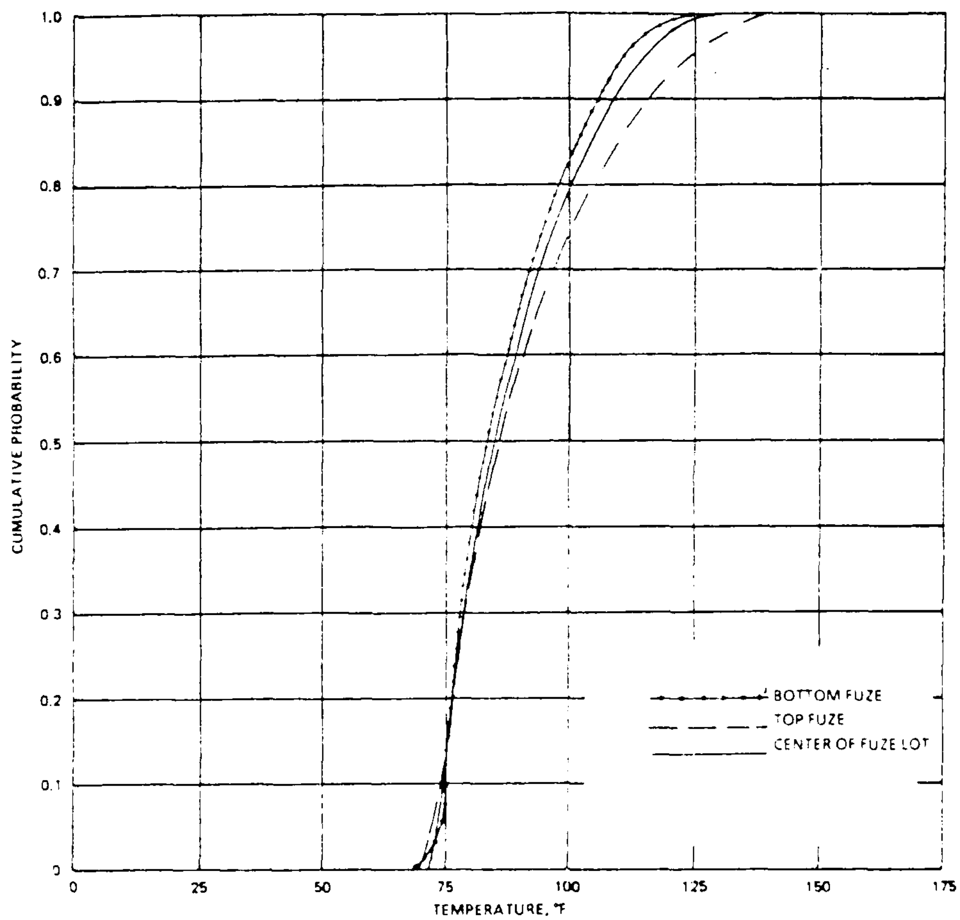

FIGURE 26. Mk 346 Bomb Fuzes in 50-Caliber Ammunition Box; 1968-1975.

The final display from the Panama exposure site is shown in Figure 27. These data depict the thermal response to the tropical sun of 30-caliber rifle cartridges. Again, the projectiles and powder were removed before shipment. Therefore, the thermal mass was about 50% of that of live, comparable rounds. Even so, the top center rounds experienced temperatures of less than 140°F. (By comparison, an identical exposure in the Mojave Desert for 10 years revealed only minor ballistic changes for Winchester ball powder in.30-06, SL, 1955 150-grain ball rounds.)

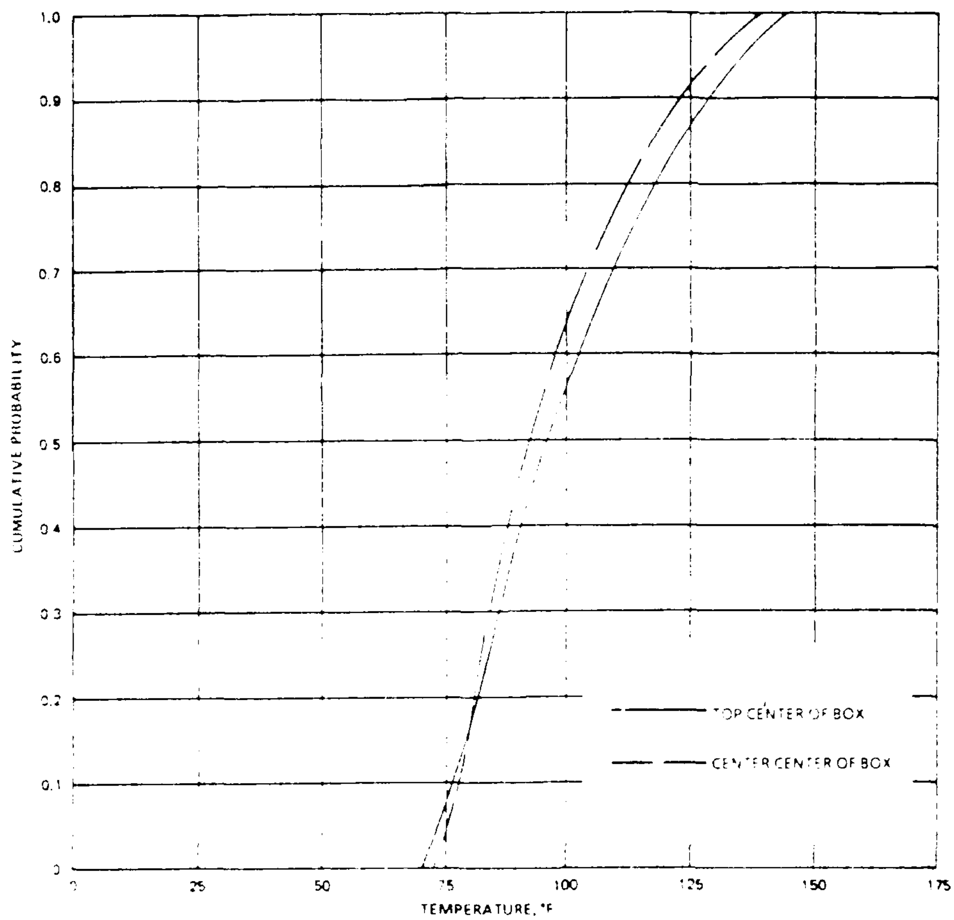

FIGURE 27. Small-Arms Brass Cases in 30-Caliber Ammunition Box; 1968-1975.

Subic Bay Measurement Site

The data from Subic Bay on the island of Luzon, in the Philippines, are less complete than data from other sites because this measurement site was located in the forward supply base for the Viet Nam theater. Therefore, the only items kept there were items that were failing in action or that were placed there for political reasons. The Subic Bay record and that from Panama are quite similar; in fact, for most purposes they are the same.

The thermal history of the surface of the chaff rocket (warhead and LAU-10 launcher) is shown in Figure 28. This rocket was a quick-response design effort because of a tactically pressing need. It was, in reality, a 5-inch-diameter Zuni rocket with an aluminum "dipole-filled" warhead. Therefore, the thermal mass was an order of magnitude less than that of the regular Zuni warhead. The curve shape shown in Figure 28 is the same as that seen in data from other tropical areas. The maximum warhead temperature was about 130°F.

Figure 29 is the baseline data on a regulation Zuni four-pack in a LAU-10 launcher-shipping container. Note that the more massive rocket motor temperature responses are less than those of Figure 28. This is an example of the thermal effectiveness of a combination of white color and "normal" thermal mass. (A single Zuni warhead-motor combination is about as heavy as one man can lift.)

The data from a prototype Shrike missile are presented in Figure 30. These two units were exposed in their regulation square gray containers. The 8-inch-diameter missile sections were centered in the containers by rubberized horsehair sections. Even though the absorptivity of the container was more than 90%, the flat-topped geometry negated the high temperatures one would expect. Perhaps this indicates that containers should be designed "square."

Figure 31 indicates the penalty to be paid when the free air space in a container is inadequate. The NOTS 5-inch Spinner was a World War II shore bombardment rocket that was resurrected for use in Viet Nam because of the need for cheap counter-battery artillery. The 5-inch Spinners were oriented with the major axis north and south, as was all the other ordnance discussed in this report. Therefore, the units were exposed to the greatest possible amount of sunshine. Figure 31 shows that the silver-colored containers allowed the Spinners to experience temperatures similar to those experienced by ordnance stored in dark-colored containers.

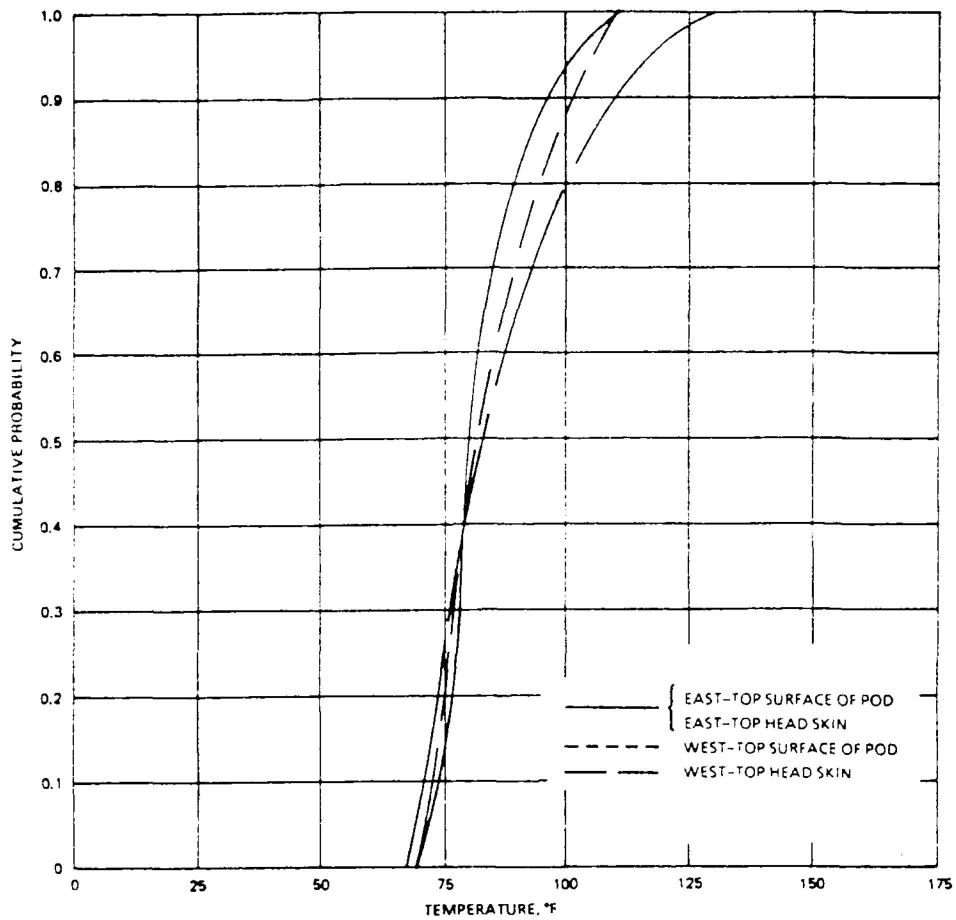

FIGURE 28. 5-inch Chaff Rocket in Zuni Four-Round Shipping Container-Launcher; Subic Bay, 1969-1970.

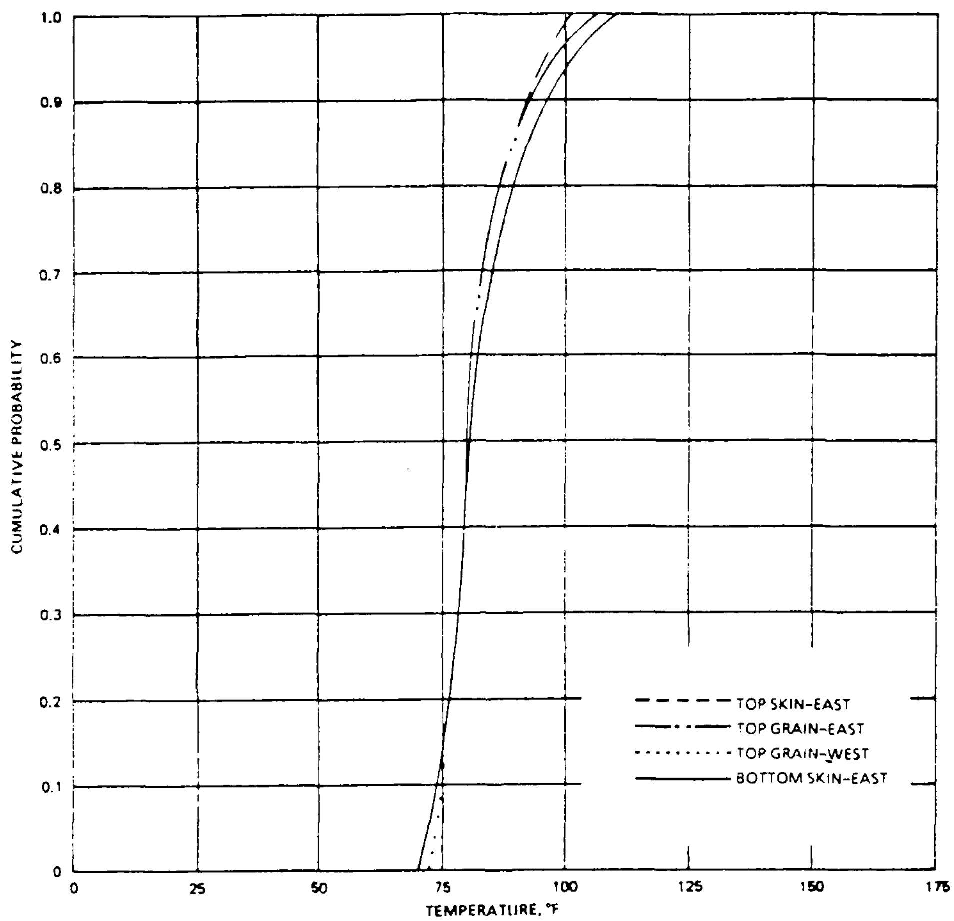

FIGURE 29. Four Zuni Rockets in Combination Shipping Container-Launcher; Subic Bay, 1969-1970.

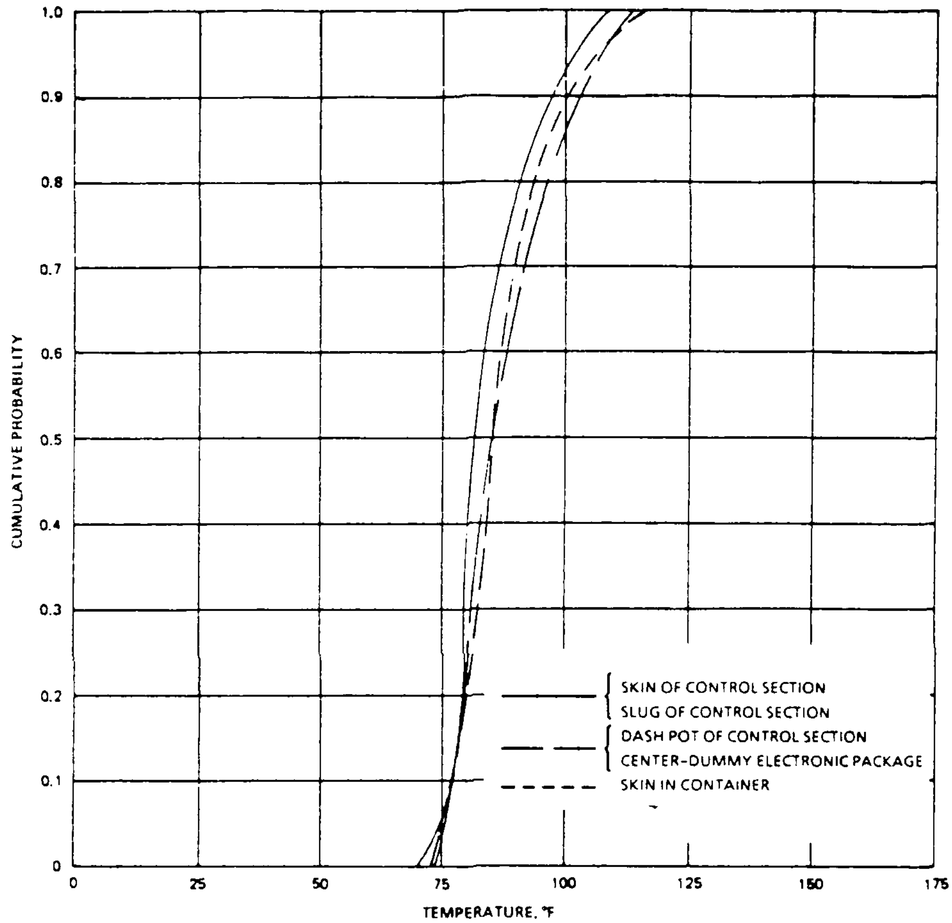

FIGURE 30. Shrike Missile; Subic Bay, 1969.

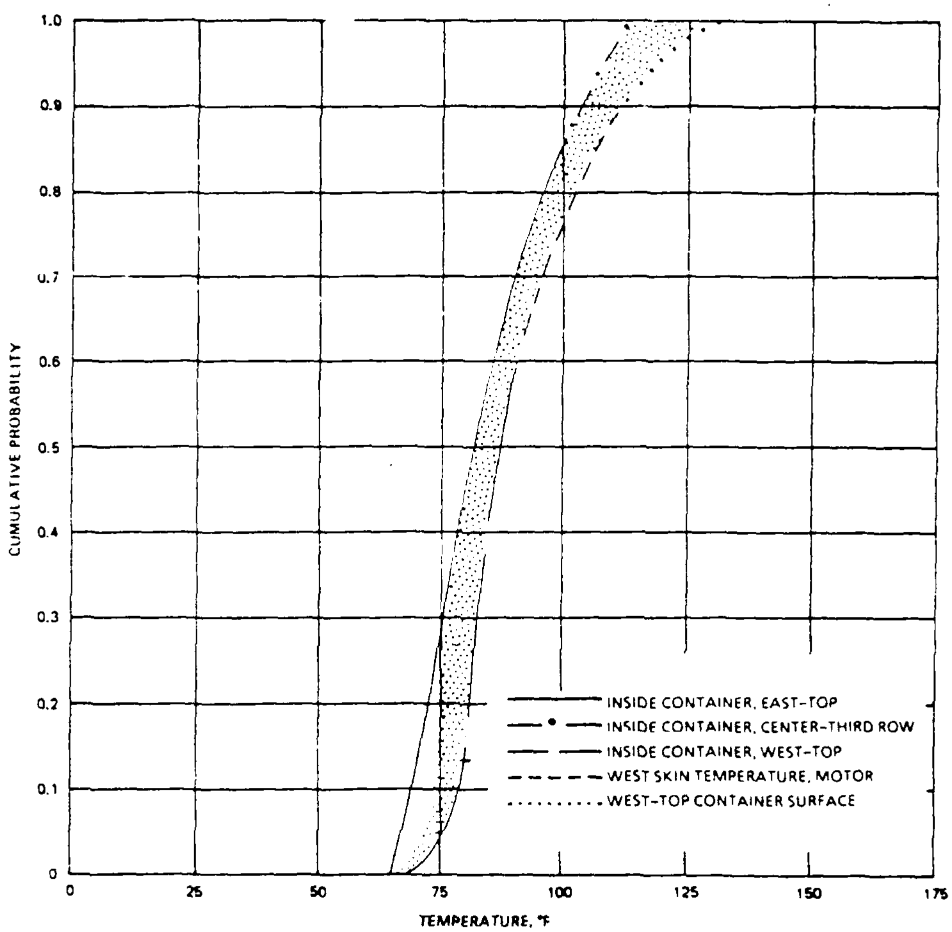

FIGURE 31. NOTS 5-inch Spinner; Subic Bay, 1967-1969, 1972.

Because some trouble with fuzes had been experienced in combat, the thermal history of some fuzes was derived at Subic Bay. The response of various fuzes to thermal exposure in the tropics is shown in Figures 32 through 35. All of these fuzes were exposed singly or in a container with a few others. Of those shown in the figures, all were in one olive drab fuze box about 1 ft^3 in volume.

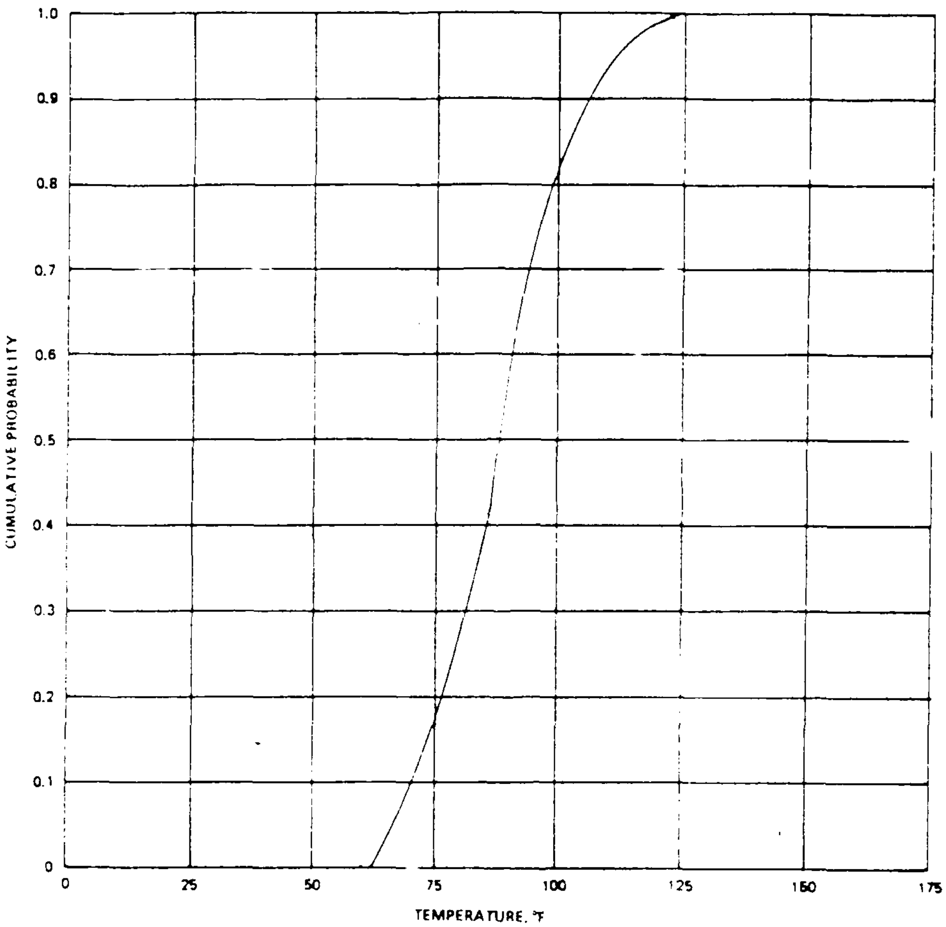

FIGURE 32. Bomb Nose Fuze (Propeller-Driven Mechanical Time Fuze); Subic Bay, 1969, 1972

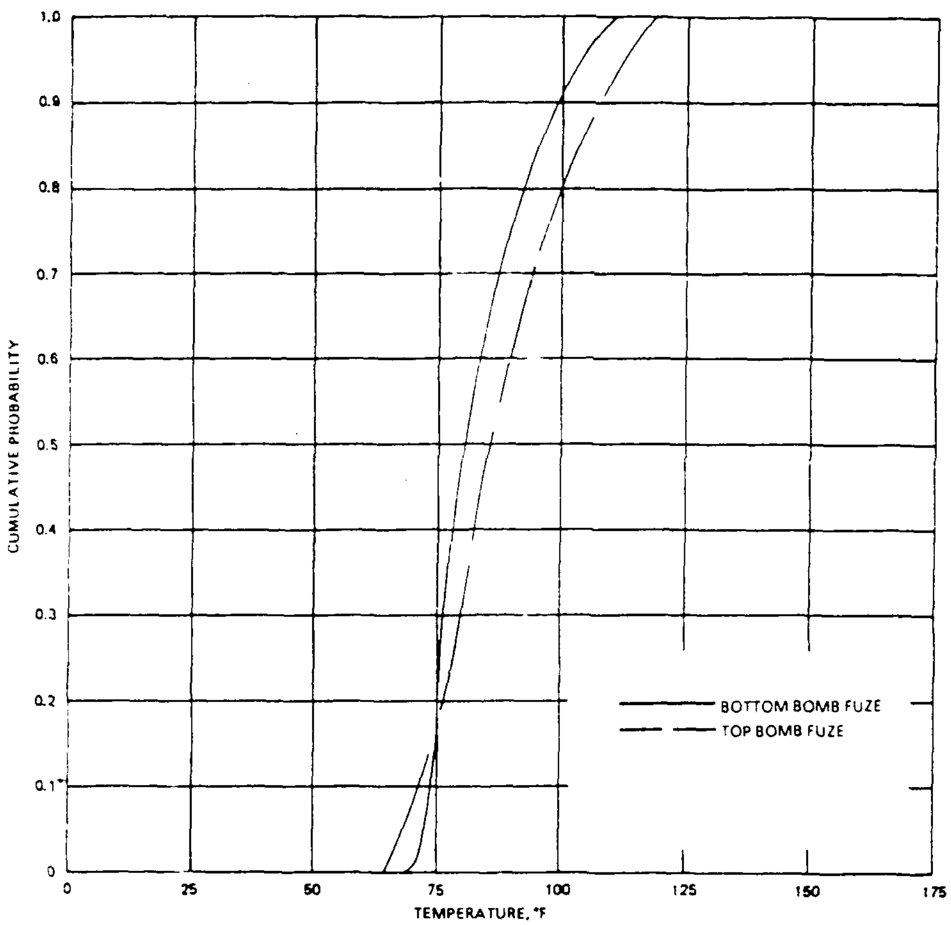

FIGURE 33. Mechanical Time Fuzes in Metal Box (M103A1); Subic Bay.

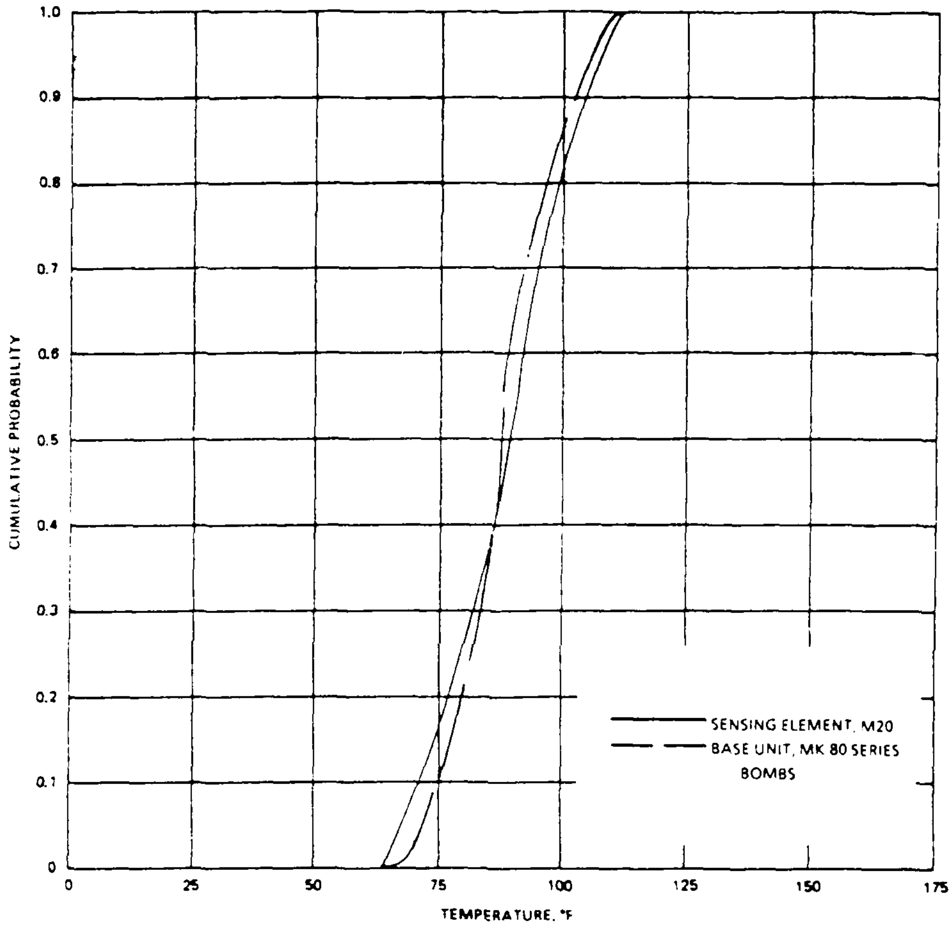

FIGURE 34. Electrical Bomb Fuze in Metal Box; .
Subic Bay, 1968-1969, 1972.

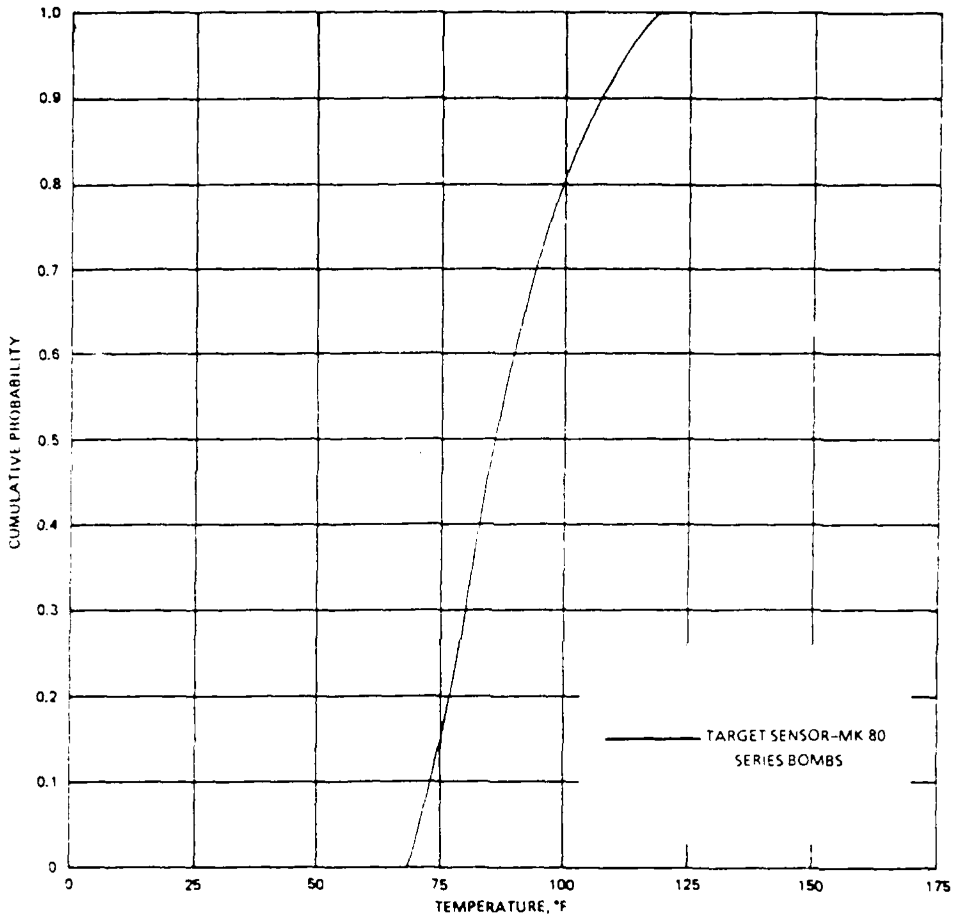

FIGURE 35. Electrical Bomb Fuze in Metal Box; Subic Bay, 1968-1969.

Figure 36 shows the thermal history of a variable time fuze mounted singly on a pallet of Navy projectiles. This particular history was made because the author had observed that, under the stresses of combat conditions, when fuzes arrived with water in the container they were disassembled and dried in the sun instead of being junked. It was felt a thermal history might be useful for future design.

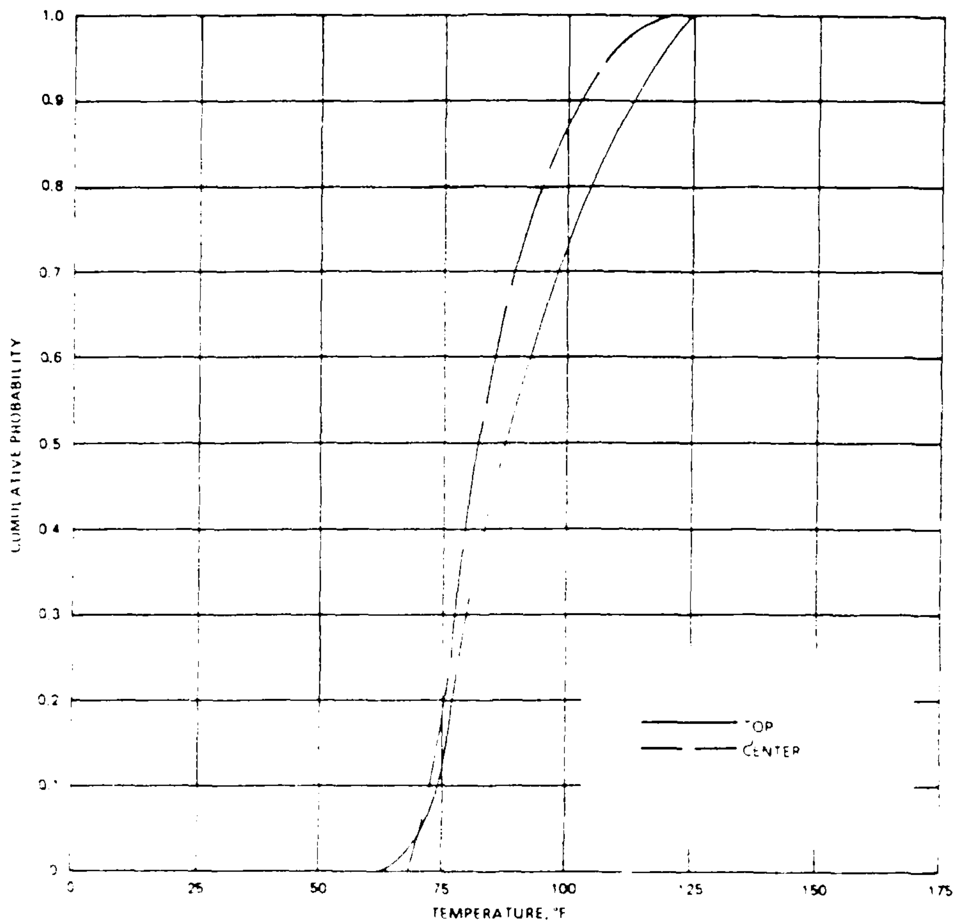

FIGURE 36. 5/38 Variable-Time Fuze, Out of Container; Subic Bay, 1968-1969, 1972.

Another wartime situation involved at-sea transfer of ordnance. Because of this situation, ordnance often was staged at dockside, out of sheltering explosive hazard magazines and out in the hot tropical sun. Figure 37 shows the data from a gun-projectile-mounted variable-time fuze. It is protected by a brass fuze cover that is screwed onto the ogive of the projectile. The projectile is standing on its base on a wire pallet, so that the fuze is exposed to the sun. Even so, the fuze cover and the thermal mass of the projectile moderate the temperature response of the fuze.

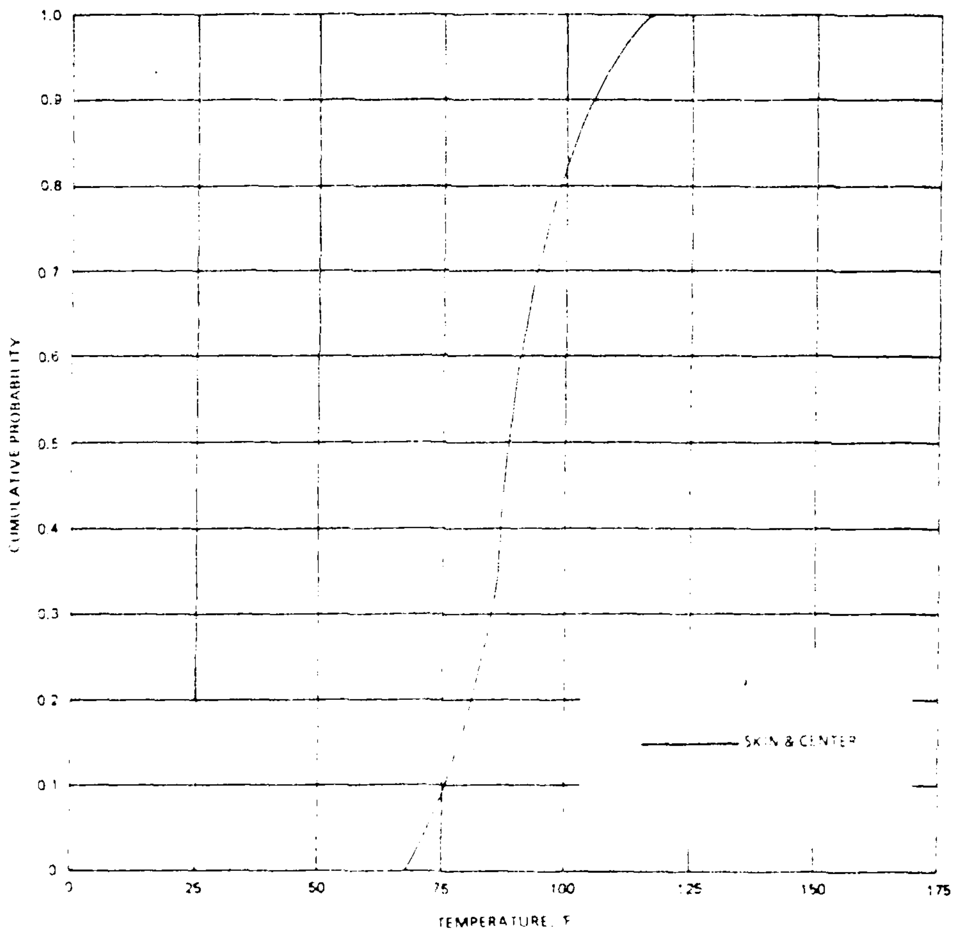

FIGURE 37. 5/54 Fuze With Brass Cover in BL&P Round; Subic Bay, 1968-1969, 1972.

Figure 38 depicts the thermal response of the outside surface of a destroyer's 5-inch/54-caliber projectile. These data are from the ogive area of the projectile only. The purpose was to determine the maximum temperature response on a projectile in tropical dump storage.

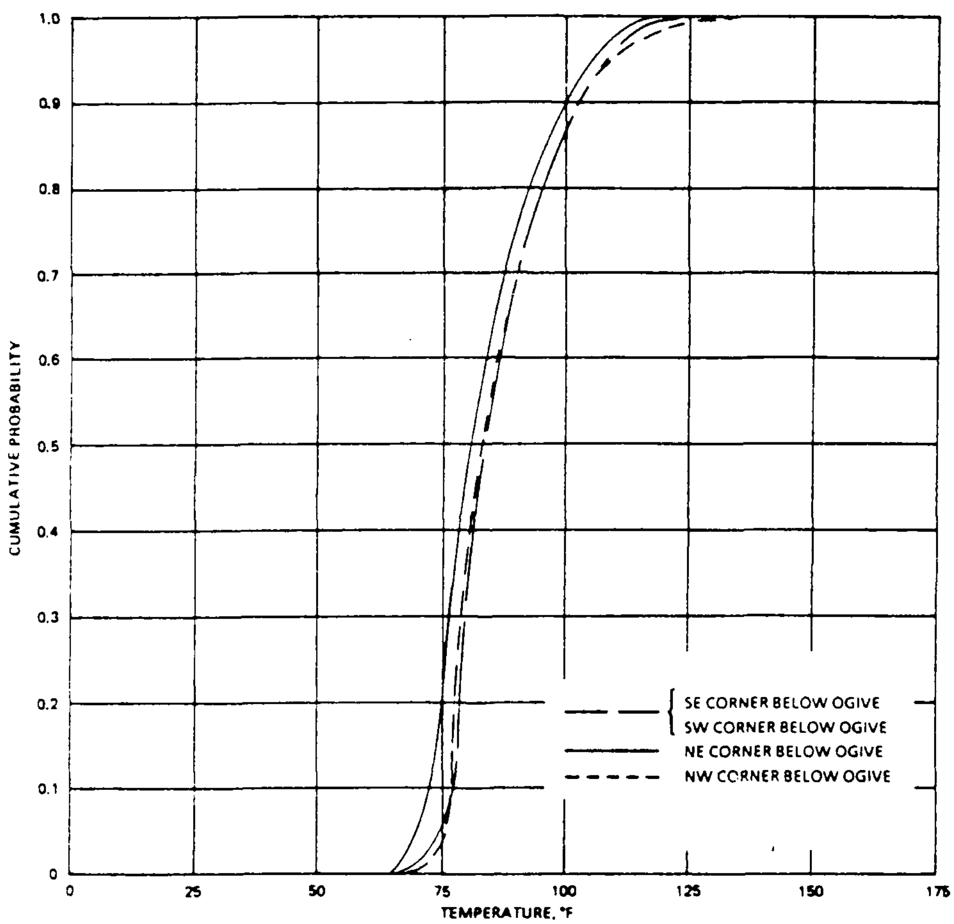

FIGURE 38. 5/54 BL&P Round; Subic Bay, 1968-1969, 1972.

Innisfail, Australia Measurement Site

The question remained as to whether tropical data from the northern hemisphere would be representative of logistic action in the southern hemisphere. Therefore, when the possibility arose, thermal data were collected in tropical Australia to make this comparison. The Technical Cooperation Program (TTCP), which includes Australia, the United Kingdom, Canada, and the U.S., supported the project, which lasted long enough to afford 1 calendar year's worth of data, plus an extra hot season. The measurement matrixes were predominantly solid rocket motors, because of the charter of the working group, but a few other units were added for more universal data.

Figure 39 shows data for 12-inch-, 5-inch-, and 2.75-inch-diameter rocket motors that are not protected by shipping containers. Surprisingly, these data and all data from Innisfail show maximum response temperatures that are higher than the Panama data would indicate. A study of the meteorological history of the area revealed that the wind blows off the ocean during the winter (June, July, and August) and the monsoon comes off the Atherton Tableland in summer (December, January, and February). The Atherton Tableland is dry desert. Therefore, the measurement site at Innisfail is tropical most of the year and quasi-desert the rest of the time.

The traces of Figure 39 are not unusual. The haze gray ASROC (12 inches) and Zuni (5 inches) are warmer than the white 2.75-inch FFAR. The diameter effect again shows up in that the 12-inch ASROC gets hotter at the 12 o'clock position than does the smaller diameter Zuni. This indicates that re-radiation to other objects is a larger fraction of the total heat balance when compared to incoming solar radiation for smaller diameter objects than it is for larger diameter objects. Also, the thermal mass versus the area of incoming radiation impingement and outgoing radiation must be considered in predictive calculations.

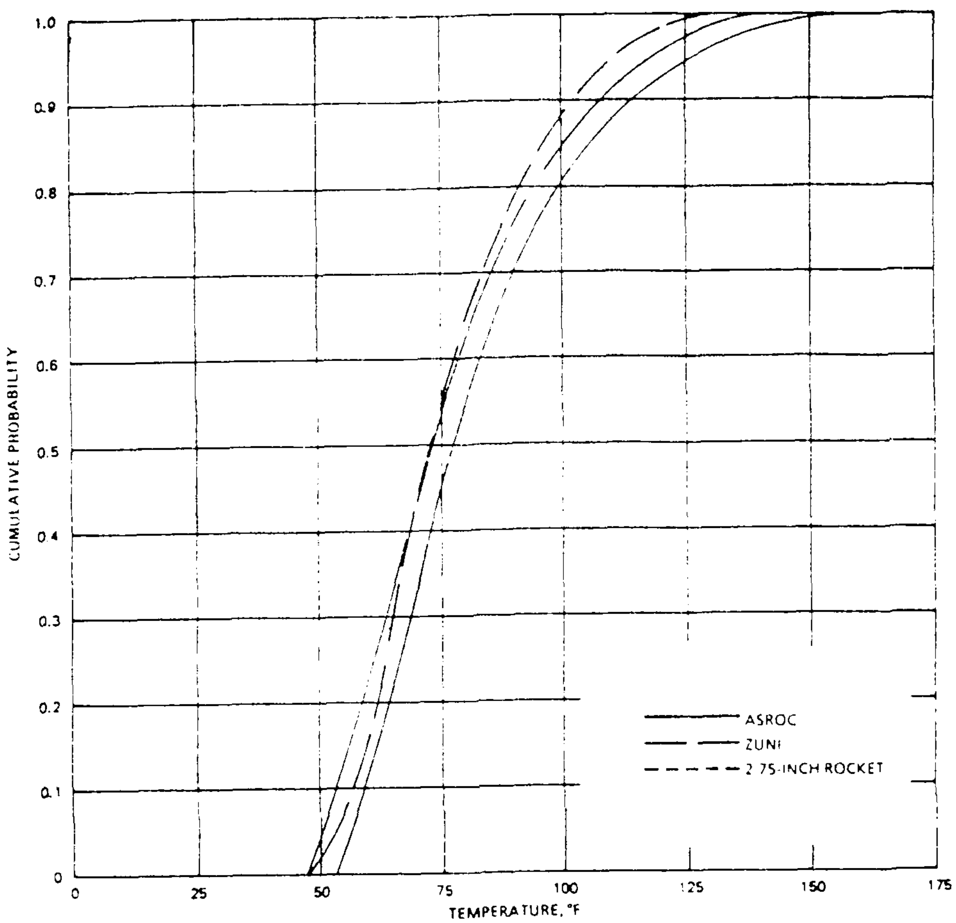

FIGURE 39. Skin and Center of Motor, Out of Container; Australia, 1971.

Figures 40 through 43 cover in-container exposure. Figure 40 is data derived from a container consisting of a group of four 3-inch-diameter tubes connected together by end plates. The color was haze gray. Figure 41 is data for a long, haze gray metal box about 8 inches square in cross section. Figures 42 and 43 are data for cylindrical, haze gray containers about 16 and 24 inches in diameter. A comparison of Figure 40 with Figures 42 and 43 indicates the previously discussed diameter effect. To the author's surprise, however, the square container of Figure 41 did not exhibit the much cooler regime that was expected. Although assured by the Australians that the data were good, the author would have discarded the data as thermocouple liftoff error, and he advises caution in use of the figure.

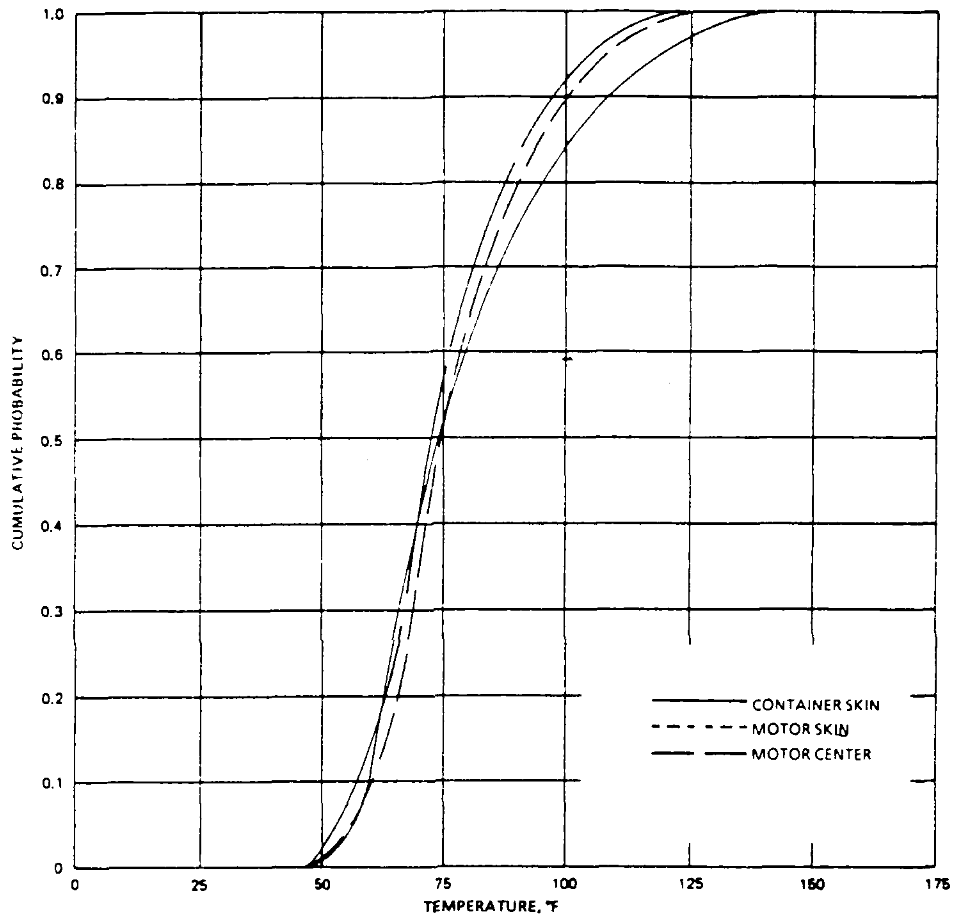

FIGURE 40. 2.75-inch Tubes in Container; Australia, 1971.

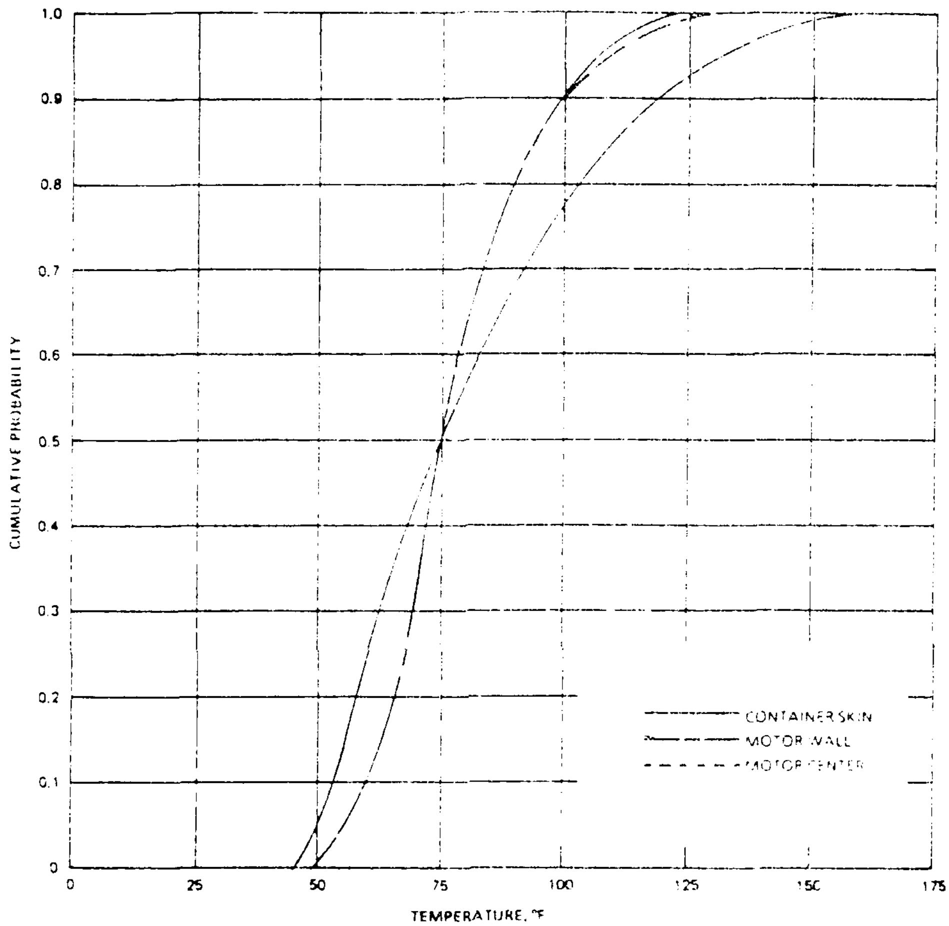

FIGURE 41. Sidewinder in Container;
Australia, 1971.

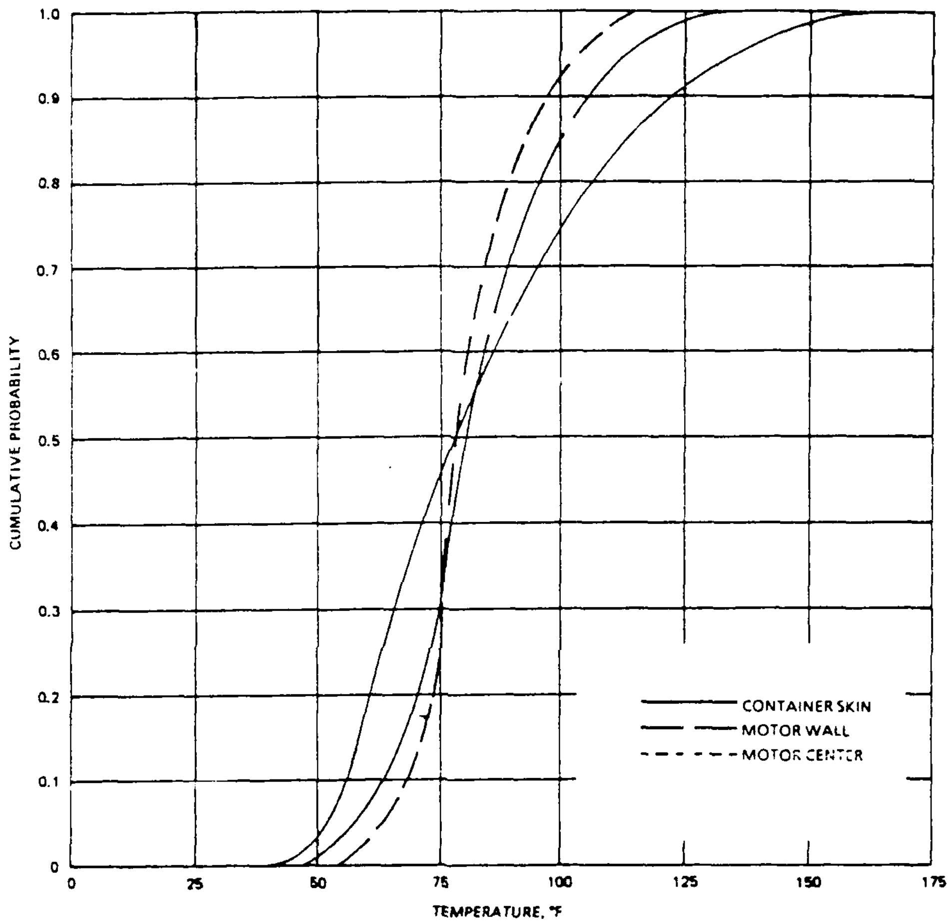

FIGURE 42. Sparrow in Container;
Australia, 1971.

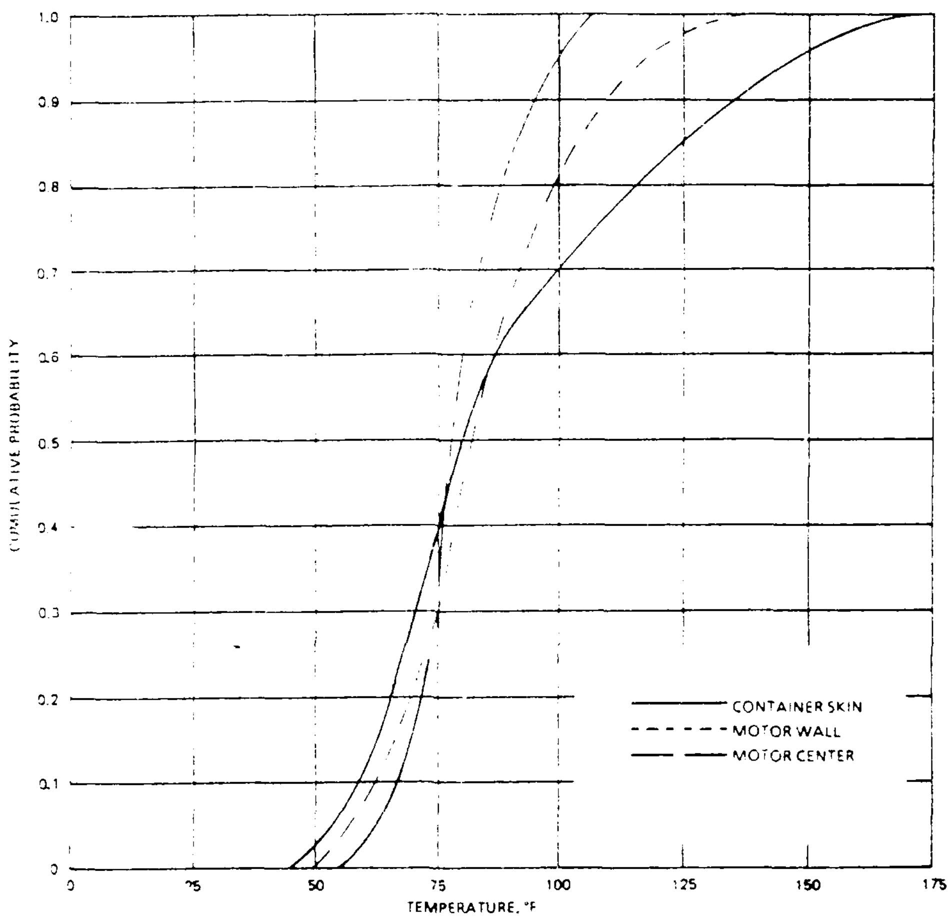

FIGURE 43. ASROC in Container;
Australia, 1971.

Figure 44 shows data from British rocket motors: the 24-inch-diameter Cuckoo, the 8-inch-diameter Linnet, and the 5-inch-diameter LAP. The British tried a different philosopny of thermocouple placement than NWC uses. They placed the thermocouples in a series through the diameter, just inches from both ends, and entirely ignored thermal end effects. (NWC placed the thermocouple series in the center of the long axis to avoid measuring end effects.) The temperature reports for the British motors are cooler in all respects than their American counterparts. The difference is a measure of how much cooler the ordnance is when measured a short distance in from the end. For that reason, the British data are of great value, particularly to anyone deriving three-dimensional thermodyanmic analysis models of rocket motors. They provide insight into the end effects present in a real-world situation.

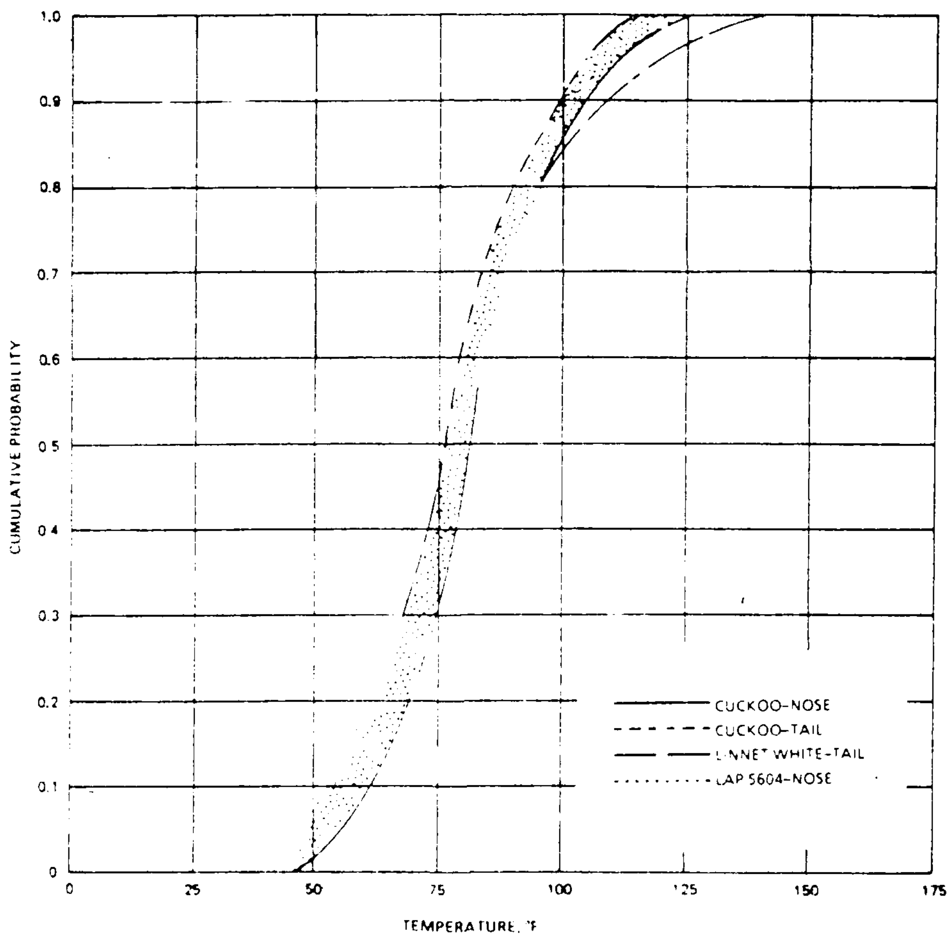

FIGURE 44. British Rocket Motors in Wooden Shipping Boxes; Australia, 1971.

As an academic exercise, an ethylene-glycol-filled, 12-inch-diameter rocket motor was exposed along with the solid rocket motors. The idea was to measure any difference in temperature due to free convection of the fluid. The data of Figure 45 indicate a much greater thermal gradient through the missile than one sees in solid rocket motors. It is concluded that great care should be exercised in assigning thermal design criteria for a liquid system.

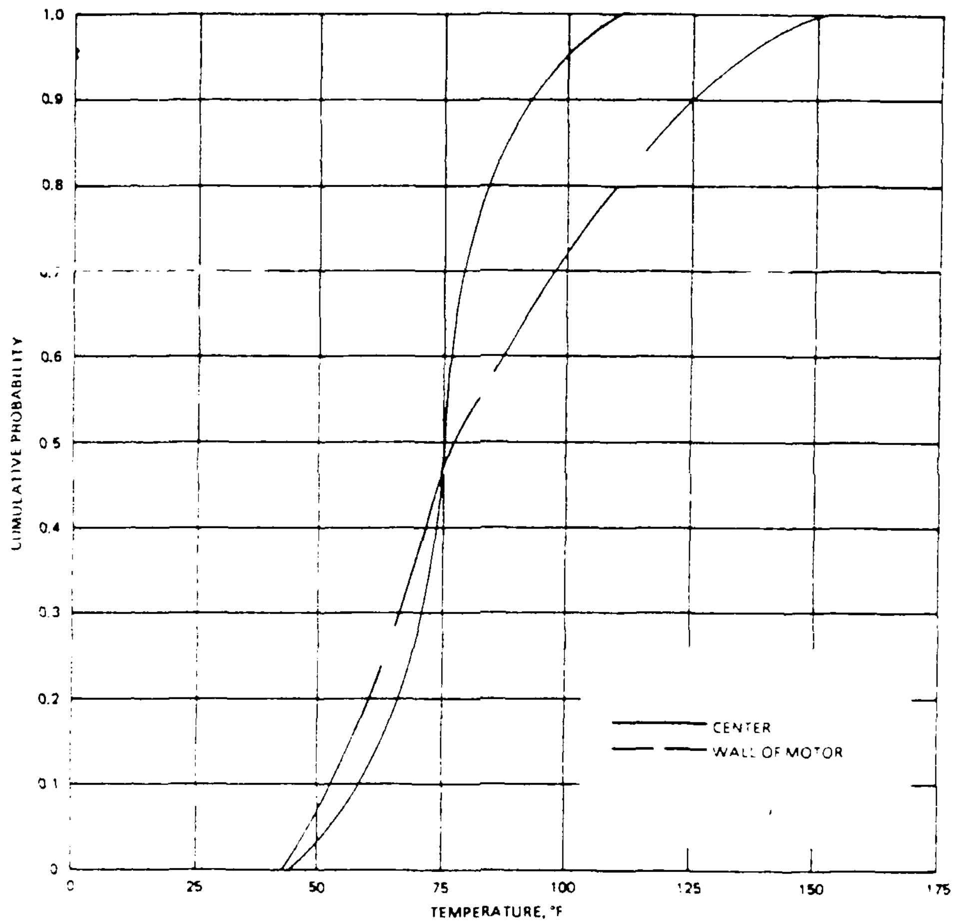

FIGURE 45. Liquid-Filled, 12-inch Bullpup Motor; Australia, 1971.

Figure 46 shows data on a nonpropulsion item--small arms ammunition. In this case, the 7.62 NATO (.308 Winchester) round was used. Again the projectiles and powder had been removed, with the corresponding loss of thermal mass. The regulation 30-caliber-ammunition metal box was painted olive drab. Even so, the temperature history is similar to that shown for other small arms ammunition at the other tropical locations.

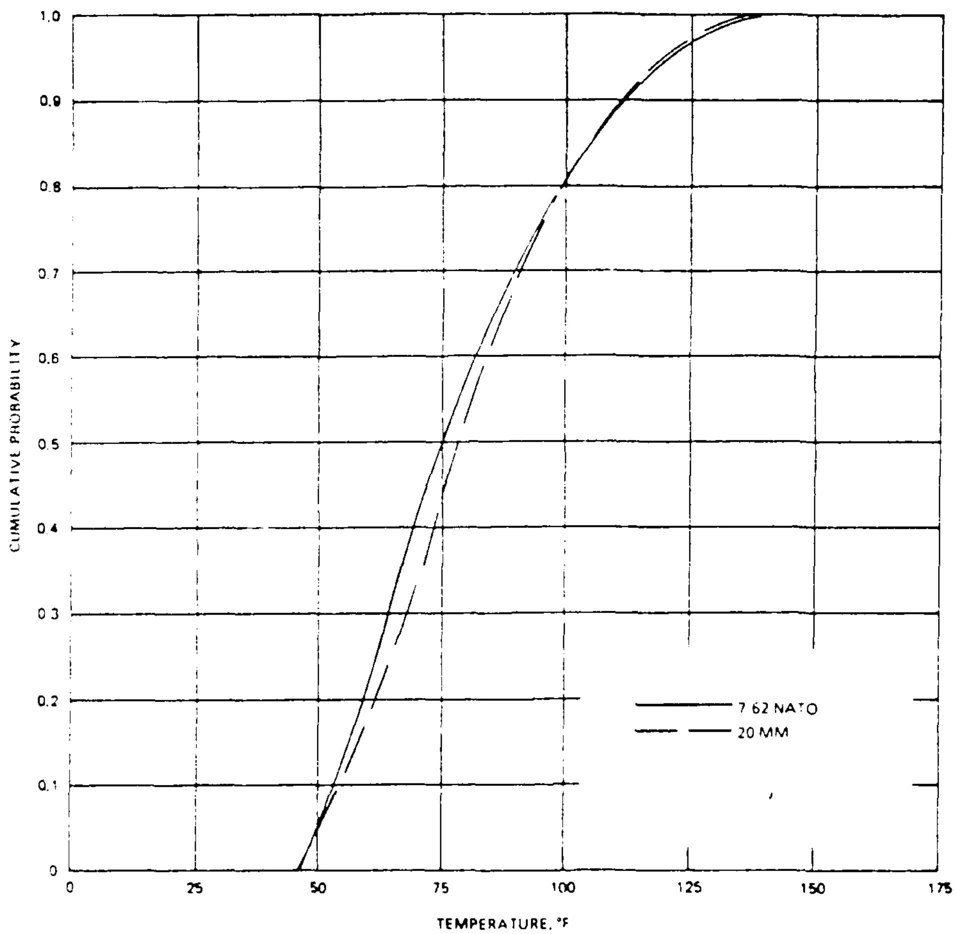

FIGURE 46. Small Arms Ammunition in 30-Caliber and 50-Caliber Boxes; Australia, 1971.

CONCLUSIONS AND RECOMMENDATIONS

The event of dump (field) storage is the exception rather than the rule during the service life of any military material, especially in the case of tactical missiles. Even so, this event must be recognized and planned for during the design phase of procurement.

Even when the item of materiel is so straightforward in design that the maximum dump storage temperature becomes the design temperature, there is no basis for using the presently popular 165°F soak situation. Even the maximum surface temperature of 165°F is outside the realm of good engineering practice for the vast majority of fielded units, as revealed by the data presented in this report.

A high-temperature, gradient-free thermal situation is unknown in the context of finite tactical weapons or most materiel in general. It is recommended that all "soak" testing be stopped and thermal gradient testing be substituted. The less likely the thermal design goal is, the greater the thermal gradient associated with it will be. Data derived from the northern hemisphere are applicable for commensurate southern hemisphere locations.

Appendix A
STOCKPILE-TO-TARGET SEQUENCE

This appendix presents a method for determining the use life of an air-launched rocket motor and consists of graphically outlining the probable life of an air-launched unit. It can be seen in Figure A-1 that, no matter what the air-launched ordnance item is, during its life span it will follow the events as depicted in the diagram.

In general, the sequence starts at the component manufacturer level. It can be assumed that the components will be built in the manufacturing centers of industrialized nations of the world. Therefore, the components will be shipped from the manufacturer to assembly depot by only four different modes of transportation: truck, rail, ship or air.

The assembly depot can be assumed to be located in a manufacturing complex, or if in a remote location, it will have the equivalent facilities of a modern manufacturing complex. All subcomponent storage will be in some type of covered area, either above ground storehouses or earth covered igloos. Therefore, the component will be protected from the adverse effects of exposure to the weather. On assembly, the units will be packaged and palletized for delivery to the fleet. If manufactured in the United States, the unit is then shipped via truck, rail, or air to one of the established Naval Ammunition Depots (NAD), situated within the continental boundaries. Once at the ammunition depot, the unit will be placed in a standard "explosive hazard magazine" as per instructions delineated in NavWeps OP-5, Volume I. Again, there will be no outside storage and a very small chance of storage in above ground storehouse facilities.

From the continental United States storage depot, the item will be either (1) sent to an aircraft carrier, (2) shipped overseas for storage or use, or (3) stored on board an ammunition ship. In the vast preponderance of situations, the unit will be transported via ship to a forward area or loaded on board an aircraft carrier for a tour of duty. During wartime, the use of civilian merchant ships is a good probability. Therefore, the use of non-Navy ships and the inherent chance of cargo mishandling must be recognized. Once at a forward storage area, three storage modes are possible: (1) igloo storage, (2) above-ground storehouse or primitive covered storage, and (3) primitive dump storage. It has been observed, even during the first hectic days of the Viet Nam emergency, that at the forward storage depots, the air-launched rocket motors and components received preferential treatment.

Where there were storage igloos, the bombs, gun ammunition, ballistic rockets and some pyrotechnics were dump-stored to provide room for the more sophisticated air-launched guided missile components. This is only an indication, but a strong one, that the air-launched rocket will, whenever possible, receive preferential treatment. However, it was also observed that the Marine air wings were forced to dump-store even air-launched rocket components at forward airfields. Following investigations disclosed that even as Butler-type huts became available, the air-launched guided weapons were given preferential treatment. The forward storage situation is the most severe portion of the stockpile-to-target sequence that a weapon can be expected to experience.

Another flow sequence (Figure A-1) shows the unit being loaded onto an ammunition ship for at-sea transfer to an aircraft carrier. This operation has become increasingly popular in the limited war situation where the aircraft carrier is used more as a Naval Air Station than a tactical weapon system as in World War II.

The land counterpart of the aircraft carrier is the Marine Corps forward airfield. In a wartime situation, a forward airstrip will be cut from the terrain and any natural hill and valley area used for dump storage of the explosive components. Usually, there will be few or no pieces of elaborate handling gear or specialized tools and equipment to transport or service the ordnance.

Since the unit is to be used in both circumstances, it should be designed so it will be usable and function when air-carried from either situation. Therefore, the more stringent environmental considerations of Marine Corps use should be given recognition. Instead of the "antiseptic" conditions of an aircraft carrier, the unit may sit in the sand, wind, and rain for a period of time before it is manhandled to the "hot line" and installed on the aircraft from which it is later launched.

A study of Figure A-1 will reveal that all variations of paths have not been discussed here. There are many possible combinations of the enumerated stations in the sequence; however, the other combinations would lead to no new environmental criteria that have not already been identified. Therefore, for brevity, they have been omitted.

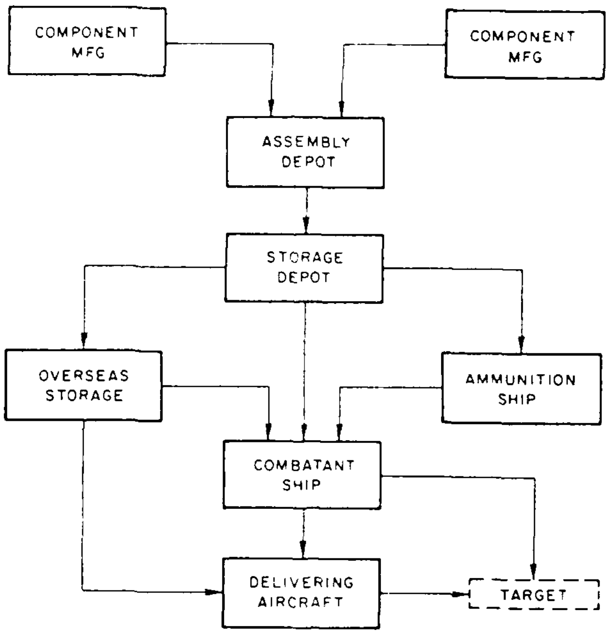

FIGURE A-1. Stockpile-to-Target Sequence.

Appendix B
DUMP STORAGE

EXAMPLES OF DUMP STORAGE

Use of dump storage is more easily predicted than is apparent at first observation. The majority of times that the Navy will resort to dump storage can be illustrated by the following two examples. In the first circumstance, a new airfield is put into operation and there are no magazine facilities available. This was the case at Da Nang and Chu Lai during the Viet Nam emergency. However, even during this emergency, the air-launched tactical missiles were given preferred treatment. In most cases, this meant that they were placed in hastily prepared revetments or covered by a canvas tarpaulin. In the second situation, the present forward staging area or Naval magazine is overloaded by the gross volume of the operation. This happened in both Korea and Viet Nam. In 1965 at Subic Bay, there were not enough available igloo magazine structures to accommodate the gross tonnage of ordnance that was being "funneled through" on its way into action. Although the personnel did an extremely good job of handling the situation, there were makeshift bamboo and canvas "shelters" (see Reference 6, page 46) and vast amounts of dump-stored ordnance for the first few years. Eventually, the required igloo-type structures were constructed and the problem became less severe. However, the fact remains that dump storage did exist for some type of ordnance for a time. Again, the more sophisticated items in the Naval arsenal were given the best treatment, as common sense would dictate.

The unforeseen times when a dump storage-type situation can and does exist were graphically demonstrated when an aircraft carrier did not make a scheduled pickup of a load of assorted ordnance (see Figure D-8 of this report). The load had been staged to the dock area and remained at least 3 weeks awaiting the ship. This particular load was staged in late April and, therefore, at 15 degrees north latitude, was exposed to the hottest portion of the tropical exposure. (The sun is directly overhead, and it is still the dry season.) It is not known how much longer this particular load remained there before it was either returned to the magazine or loaded on an ammunition ship or aircraft carrier.

The aircraft ordnance hot line also approximates the dump storage situation. In forward areas, the squadron ordnance personnel will draw the projected ordnance for a limited number of strikes. They will then remove it from the container. where appropriate, and assemble it as necessary in readiness for the installation on the aircraft. Generally, this phase of operation is of short time duration.

EXPOSURE PHENOMENA

In this measurement series, the dump storage situation has been reproduced with the intent of simulating the extreme situation. The candidate ordnance was exposed singly, in close approximation with, or directly situated on, the ground. The ordnance when in containers, or exposed bare, was positioned with the longitudinal axis pointing nominally true north and south. The geographic location of the exposure sites also was carefully selected for the maximum exposure potential. Since it is recognized that the extreme year does not occur each year, the ordnance has been left in these locations indefinitely.

Single Exposure

The general situation for exposure of ordnance in the combat-oriented storage dump is in like item groups (see Figures D-5, D-6, and D-7 of this report). There is not enough room in the Naval magazines to spread out a shipload of tactical missiles, and in the airfield storage dump situation, the larger the magazine area the bigger the target. Therefore, the containerized or palletized ordnance is stacked about as high as is possible with a forklift or as the surface will allow before the stack becomes unstable. This tends to compact the units into the most easily accessible, most volumetrically efficient grouping commensurate with revetment height, soil conditions, and terrain features. Therefore, the thermal mass is much more than that of a single unit. Because most containers are constructed of metal, the conduction of heat from the warmer containers to the cooler would seem to become of importance in not allowing the exposed edge units to respond as quickly to extreme exposure profiles as the singly exposed unit would in the same set of meteorological circumstances.

The analysis can be taken one step more if the exposure is explored in more detail. The single unit is exposed to the sun from just after sunrise till just before sunset. However, the point of normal exposure to the direct rays of the sun changes almost 180 degrees from sunrise to sunset. Therefore, the thermal gradient through the item will tend to do likewise.

Now, if a stack of 100 units in contact with each other is examined instead of a single unit, the following is observed. At sunrise, the east side of the stack is fully exposed. As the day progresses, the top of the stack replaces the east side in exposure to the direct rays of the sun. After solar noon until sunset, the west side becomes more and more exposed to the direct rays from the sun, relieving the majority of even the top units of the stack of the solar load. However, these west side units are "cold" until shortly after solar noon.

It can be seen that the central units of the stack cannot be seriously exposed for any length of time at all. They will probably only assume the general thermal energy level of the free circulating ambient air. The east side units will only be expected to achieve slightly higher temperatures than the "cold" center. Therefore, it is the west side or the top row that could be expected to exhibit a maximum thermal profile. Since the west side units receive no direct sunlight until the day is half over, they will not exhibit maximum temperatures, so this leaves only the top row. Now, the units of the top row will be expected to progressively shade the units to the east as the sun goes from the solar noon position to sunset. This shading and the thermal conductivity will tend to modify the exhibited thermal profile of even these fully exposed units, except for the top, west round. The high temperatures of this unit can only be moderated by conduction. Since the maximum temperature of a single unit occurs at about 1600 hours daily, it can be assumed that if any unit in the stack approaches the single round exposure temperature profile, it will be the top, west corner unit.

North-South Orientation

The above assumption is made on the premise that the stack is oriented with the longitudinal axis of the ordnance pointing directly north and south. If the stack was placed in an east-west orientation, the morning rays of the sun would hit the ends of the shipping containers, not the sides. Since the surface area per unit would be so small, there would not be a large enough quantity of heat available to penetrate into the containers to start the temperature rise necesary for maximum possible exposure. The only time during the whole day when a normal exposure would occur would be at solar noon when the top row is subjected to the maximum possible heat flux. However, the normal exposure would be cut down progressively as the sun's position changed until sundown.

More should be said about the effect of container to container conduction. The usual configuration of a missile inside of its shipping container is such that it is almost completely surrounded by dead air. It is true that solar irradiation will cause thermal siphon to move the air, but even this effect is not as efficient at removing heat from the container wall as the conduction of heat through the metal of one shipping container to that of the one beneath or next to the hot unit. Therefore, the container metal would preferentially receive the excess heat instead of the enclosed missiles.

Ground Contact

The missile will tend to reach more extreme temperatures for a given situation if it is in contact with the ground instead of being elevated from contact with it. Some of the more obvious reasons for this are as follows: (1) The reflection from the earth as a whole is about 50% of the sun's energy that strikes it. For desert sand, the reflectivity is even higher. (2) The velocity of the wind decreases nearer the surface. (3) The conductivity of dry dirt is about the same as an insulator. Soil temperatures as high as 160°F have been measured in the first 0.125 inch of earth surface; however, 2-6 inches below the surface, the soil is about the same temperature as the average air temperature. Only 12 feet below the surface at China Lake, the year round temperature is 70 ± 5°F, with the maximum seasonal temperature shifted 3 months. In Japan, only 26 feet below the surface, no temperature change is measured.

Due to the above, the unit sitting on the ground receives reflected radiation from the ground, cannot give off heat by conduction quickly to the soil, and is not as apt to be cooled by the prevailing breeze.

Geographic Location

It is not generally recognized that all field exposure is not equally conducive to the chance of occurrence of maximum, or extreme, thermal exposure. In most people's minds the desert, for example, is either the man-killing place they endured when driving from coast to coast during last summer's vacation or the shifting hot sand dunes of the Sahara Desert of the "late-late show."

The facts are more apparent to the personnel of NWC since it is located in the Mojave Desert. The desert is generally less severe, during the summer season, as the altitude increases. In the great depressions in the desert surface, or valleys ringed with mountains (for example Death Valley), extreme temperatures are experienced; however, some desert mountain areas and high plateaus are very comfortable in the summer. (It is interesting to note that the high temperature of 134°F ascribed to Death Valley has been reported only one time.) Therefore, it may be shortsighted to design military, or even civilian, equipment to the worldwide extreme.

The other major error in understanding is caused by the reality of human comfort. A summer day in humid Washington D.C. can be much more severe than a higher temperature dry day at China Lake, in the context of human comfort. However, the ordnance does not transpire, nor does it generate internal heat. No matter what the amount of moisture in the air, the unit is concerned only with the air temperature, solar radiation excepted. The lack of understanding of this has led many World War II ex-GI's now in the military-industrial complex to earnestly state that the South Pacific is as hot as any place on earth. In the human context this may be true; in the context of ordnance it is not.

In summary, it must be stated that the values given in this report can be considered conse vative in light of the customary military use of the air-launched tactical missile.

Forcing Functions

A word should be said about the importance of the various factors that contribute to the overall heating, or cooling, of exposed ordnance. In the past, investigators have tried to predict the importance of the various meteorological and geological heat sources and, in most cases, have not been too successful.

The most important source of heat, and the only one that leads directly to the extreme hot temperatures, is direct radiation from the sun. Even so, for the maximum heating rates necessary to yield the higher ordnance temperatures, all the heat sources must be considered. The second most important source is reflected radiation. This is usually a reflection of direct sunlight off a towering cloud bank sitting on a line of hills or mountains surrounding the valley in which the ordnance is exposed. The other forcing functions have little influence in an active sense on the high ordnance temperature situation. The most commonly mentioned of the other heat sources are outside air temperature and wind velocity. Ground reflected radiation, geologic heat and reflected radiation from other bodies have also been mentioned, but not much can or has been done with these inputs. Again, it must be stressed that only direct and reflected radiation can lead to an ordnance temperature greater than that of the outside air. Therefore, all other situations can only modify the radiation-induced situation. For example, if the maximum radiation possible for the latitude is exhibited with plenty of focused reradiation, and a brisk wind is blowing, then the ordnance skin will not show temperatures much above that of the moving air. As a rule of thumb, the maximum ordnance temperature situation will not be demonstrated if the wind velocity is above 5 knots. (Also, there cannot be a spasmodic cloudy sky condition that at times blocks the sun from the ordnance.) For these reasons, the general meteorological-calculated approach to the daily profile of ordnance temperatures has not been successful.

PROBABILITY OF DUMP STORAGE

Another facet that needs recognition is that the stockpile-to-target life of a weapon is such that it is not dump stored for extended periods of time. In the case of even conventional freefall weapons, the rate of expenditure in a use situation is such that they do not remain in the Naval magazine for any length of time. If they do, then the use rate is down and the volume of that type of ordnance is such that the units are placed in covered storage.

The chance of any given weapon, or the entire fleet purchase of units, being exposed to the maximum dump storage situation must also be investigated. If the supposition that the unit life is as much as 3% dump storage, then this 3% value must be interpreted in the cyclic context. Since the majority of wars have been fought in the temperate and tropic zones of the earth's surface, this situation in all probability will remain the case. The 365-day year is an occurring cyclic relationship. On the earth's surface, there are only a limited number of places where the ocean or other large body of water does not influence the climate. Of the remainder, not many are wind free.

DISCUSSION

Now an attempt will be made to loosely join all the factors. Three percent of a 365-day year is roughly 11 days. If the logistical pressure was so great that the unit was indeed dump stored at all, it would be expended before the next yearly cycle came around. Therefore, only one 11-day exposure is recognized. Now the unit must be dump stored in a pure desert situation, in an area not under a marine influence. This eliminates all Naval usage and all but helicopter borne Marine and Army usage. Now, for the land Army storage situation, the chances of a conflict taking place in the hot portion of the year, if indeed it is to be fought in the desert, can be related to the months of June, July, and August. Granted, portions of some May and September months are fairly warm, other portions of some June, July, and August months are cool. Therefore, only one-fourth of a yearly cycle is assumed to provide the situation in which values as herein stated could be experienced.

If a shipment of 100 weapons is used as the quantity that is dump stored, the two areas where this would take place are a front line support airfield or a naval magazine. The method used to stack weapons this size is shown in photographs taken at Da Nang in 1965 (see Appendix D). Ordnance is stacked so that it can be retrieved from either end of the pile. The height of stack is four units for the Zuni LAU-10 launcher. Discussions with magazine personnel indicate that for rough ground the limit is three to five units high if the shipping container is as stable as that for most tactical missiles. In the naval magazine, the stack height is dependent on the reach of the forklift. The ground is usually covered with asphalt and is not irregular.

Given the "Da Nang" situation, the 100 rounds would be stacked four high in a single row. Therefore, only 25 of the 100 would be exposed to any appreciable solar radiation. In the most extreme situation, the pile would be oriented with the weapons' longitudinal axis north-south. Then, only one out of the 100 units would have a chance of being subjected to the total heat load.

In summary, the following conditions exist: (1) only a 3% chance of any dump storage, (2) only a 1/4 of a year cycle capable of full exposure, and (3) only one unit in a stack of 100 capable of receiving maximum solar radiation for enough of a diurnal cycle to reach maximums; then

$$0.03 \times 0.25 \times 0.01 = 0.000075$$

or 0.0075% chance of exposure of any one weapon used in the pure inland desert.

This would seem to indicate that the dump storage situation has been overemphasized.

Appendix C
THE USE OF SILICA FOR INERT MOTOR GRAIN SIMULANT

by
Jack Pakulak, Jr.

Special casting of an inert case-bonded rocket motor presents many problems. The first is time; it takes weeks to schedule, fabricate, pour, cure, and deliver a single motor. The second part is cost; to place thermocouples in an amorphous mass while casting a motor is difficult. Precision placement usually cannot be accomplished. To circumvent these problems, it was decided to try and find a propellant simulant. Thermal diffusivity was singled out as the single most important property in a simulant. If the thermal diffusivity of a simulant were equal to that of propellant, then measured motor responses would be equivalent for both propellant and simulant.

Thermal diffusivity (α) is equal to the thermal conductivity (k) divided by the product of the density (ρ) and the specific heat (c) or:

$$\alpha = \frac{k}{\rho c}$$

For example, the thermal diffusivity of the polybutadiene propellant family in general, and RDS-507 PBCT specifically, is as follows:

k = 0.20 Btu x ft/hr x ft^2 x °F

ρ = 108.8 lb/ft^3

c = 0.29 Btu/lb x °F

0.04 in^2/s in 1 ft^2/hr

Therefore, the thermal diffusivity (α) is as follows:

$$\alpha = \frac{0.2}{108.8 \times 0.29} \times 0.04 = 2.53 \times 10^{-4}\, in^2/s \text{ or } 1.63 \times 10^{-3}\, cm^2/s$$

The above values for the physical constants were obtained from data contained in the CPIA M-2 Propellant Manual and from data measured by Jack Pakulak at NWC.

The most workable, easily obtained, and least expensive simulant turned out to be desert silica blow sand from NWC's desert facility. The physical constants of the silica sand are as follows:

$k = 0.19$ Btu x ft/hr x ft^2 x °F

$\rho = 103$ lb/ft^3

$c = 0.18$ Btu/lb x °F at 100°F

Therefore, the thermal diffusivity (α) is as follows:

$$\alpha = \frac{k}{\rho c} = \frac{0.19}{0.18 \, x \, 103} x \, 0.04 = 2.50 \, x \, 10^{-3} \, cm^2/s$$

The above values for the physical constants were obtained from data found on pages 451 and 461 of Reference 25 and from data obtained by Billy D. Martin of NWC from measuring the sand used in the simulation.

These data will also allow the use of thoroughly dried silica sand as a propellant simulant for other types of motors. The specific heat value for silica varies linearly along the following matrix:

$c = 0.1667$ at 32°F

$= 0.2061$ at 212°F

$= 0.2315$ at 392°F

The density of silica sand can be varied through particle size manipulation. The value will vary from 87 lb/ft^3 to a normal value of 102 lb/ft^3 to a dense maximum of 156 lb/ft^3. The density can therefore be varied at will to fit the necessary value.

Table C-1 was excerpted from References 26 and 27.

Table C-2 provides some typical values of propellant and explosive mixtures. As seen in Table C-2, an approximation of 0.0003 in^2/s can generally be used for the thermal diffusivity of propellants

TABLE C-1 Density of Sand.

Sand	Density, lb/ft^3
Dry, coarse	87-93 5
Dry, fine	87 103
Moist, fine	118-128
Sandstone	137-156

and explosives. Silica sand at 0.0004 in^2/s, then, is a reasonable inert simulant for the thermal response of rocket motors and warheads.

TABLE C-2. Some Propellant Characteristics.

Family	k		c	
	ψ (Btu x ft)/(ft^2 x hr x °F)	ρ lb/ft^3	ψ (Btu)/(lb x °F)	ρ lb/ft^3
HBX-1 explosives				3 56 x 10^{-3}
Inhibitor				2 0 x 10^{-3}
Double base propellants	0 12	104		1 4 x 10^{-3}
C55A PBCT	0 19	111	0 3	2 28 x 10^{-3}
Polyurethanes	0 25	111	0 29	
Polysulfides	0 15-0 3	105-111	0 26	

This method of thermal analysis was suggested by Warren K. Smith of NWC.

The dry blow sand has been empirically shown to be equivalent in thermal response in field trials since 1970 at NWC. A set of graphical comparisons of case-bonded rocket motor response is available in NWC TP 5365, References 28 and 29. Other documents consulted during this study are included as References 30-33.

Appendix D
TROPIC AND JUNGLE DUMP STORAGE

The problems involved in physically establishing a tropical dump storage site are detailed in this appendix. In the first place, material is not dump stored in the tropics unless it is of tactical necessity. Therefore, choices of sites cannot be made on the basis of ideal environment. Vegetation, soil, climate, and insects will create problems.

Figure D-1 illustrates a typical jungle clearing (the illustration shows Suki Rat, in southeast Asia). The grass is almost shoulder height; at times, it can be over a man's head. It is characterized by 1/2-inch-thick, razor sharp blades, 2 to 5 feet high. This grass also is cover for many less than friendly insects. The soil is usually China Clay, which consists of aluminum oxide, silicon dioxide, ferric oxide, and water. (NWC TP 5170, (Reference 24); Table 1 (page 13) describes the composition of tropical soil in any area of interest.) When dry, China clay will break down into very fine dust. In fact, NWC TP 5170 indicates that at Da Nang the sample measured out at 14-micron mean particle size. This size particle will go into painted surfaces and cannot be washed or wiped off.

When China Clay is wet, it is not a good base on which to drive a truck or other material handling equipment. At Da Nang, the entrance into the dump storage site was stabilized by throwing steel shipping pallets into the quagmire until a truck could navigate through. Needless to say, the jungle clearing will not retain its grass very long if material is moved into it. Even if the engineers didn't run a bulldozer through the clearing to level the low spots, day-to-day operations would make short work of any vegetation.

It must be stated that dump storage sites are not meant to be permanent installations. They are a field expedient and can be abandoned as the tactical situation requires. However, at Da Nang the dump storage site showed sign of being used by the French, whe ietnam was French Indochina. The United States also used it until the end of the war, which indicates that a dump storage site can end up as somewhat permanent.

Figure D-2 is a view of the "road" leading into the clearing of Figure D-1. Notice the thickness of the foliage that surrounds the clearing. It is not unusual to find three or four tier canopy jungle

FIGURE D-1. Typical Jungle Clearing.

in such situations. As can be seen in these figures, these photos were taken in the dry season. The foliage would be even more dense if it were the rainy season. (More detailed information on the natural science aspects pertaining to jungles of the world in general, or any given site in particular, is available from the Earth Topographical Laboratories (USAETL-GS-E) at Fort Belvoir, VA.)

It was intimated above that there were insects to be taken into consideration. Figure D-3 was not taken in Southeast Asia, but at the Naval Magazine in Guam. This ordnance was once hermetically sealed fuzes. As can be seen in Figure D-3, termites have gained entrance into the shipping box and the fuze cans. A close inspection of Figure D-3 reveals that the termites have brought soil into the "hermetically sealed" fuze cans and constructed typical dwellings. Figure D-4 is another view of the destruction detailed in Figure D-3. Of course this material is of no use at all to the combat troop. (More information on how to deal with insects, fungus, and bacteria, is available from White Sands Missile Range (STEWS-TE-AE).)

Figures D-5, D-6, and D-7 show the "working" dump storage facility that served the air base at Da Nang. In Figure D-5, tire tracks can be seen. This figure is again a dry season picture. The tire tracks are evidence that the China clay is breaking down into very fine particles. These particles had already permeated the white surface of the four round Zuni shipping container/launchers shown in Figure D-5.

Figures D-5 and D-7 show that, in a working storage dump, ordnance is not singly stacked. Rather, as much as can be placed in the least volume is the norm. This is one of the situations in which real world dump storage thermal data differs from data measured for purposes of this report. All the thermal measurements were taken on single units, single four-round units, or only a pallet of ordnance. However, the larger the mass, the less severe the thermal profile will be. Therefore, any data herein detailed can be viewed as "conservative."

FIGURE D-2. Typical Jungle Road (Dry Season).

FIGURE D-3. Termite Damage in Fuze Cans at Tropical Storage Site.

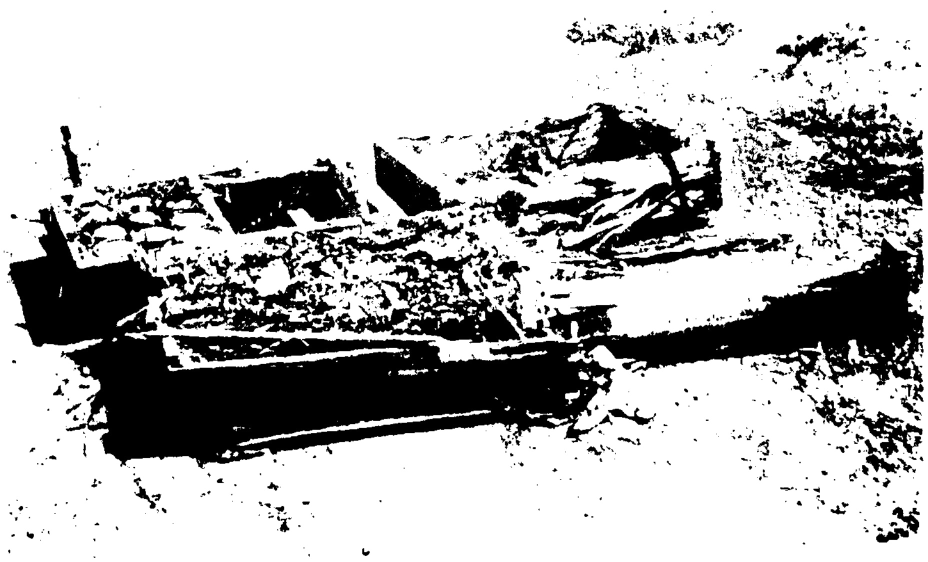

FIGURE D-4. Damage to Stored Equipment From Insects (Guam)

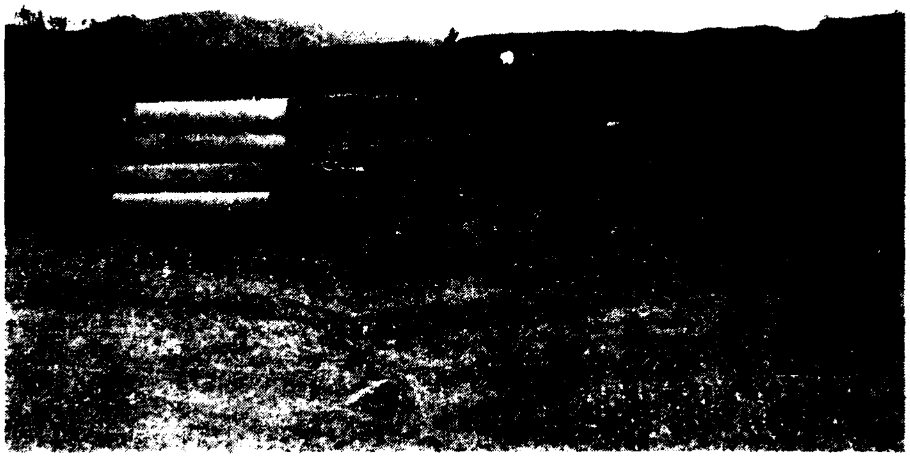

FIGURE D-5. Dump Storage Facility, Da Nang; Tire Tracks Indicate Breakdown of China Clay.

FIGURE D-6. Dump Facility at Da Nang Showing Guard Post.

Attention is drawn in Figure D-5 to the high dirt walls enclosing the material and to the two "indents" on the top of the wall. The author learned that these were heavy weapons emplacements. They were the last-ditch defense positions for the stored ordnance.

Figures D-5 through D-7 reveal that, wherever possible, the ordnance classes are not mixed. That is a reason why Figures D-5 and D-7 show much ordnance, and Figure D-6 shows only a few flares. (Figure D-6 also shows the guard post.).

Figure D-7 is an indication of what can happen in a dump storage situation. In this case Mk 82 low-drag 500-pound bombs are shipped in six-unit pallets (rear of picture). The bombs are no good to the squadron without fins to assure a straight drop to the target. The pallets were designed so that the base of these bombs was covered. That meant that the ordnance had to be unpalletized to install the fins (front of picture). Inspection of the bottom row of installed bomb fins shows that they are all hard on the ground and that they have the weight of three equal size bombs on top of them. The bottom two fins of each bomb in the bottom row bomb are bent. A bent fin is known to cause a bomb to veer off course and miss the target. In this picture, one-third of the bombs are potential misses. If the designer of the pallet had been aware of the physics of the dump storage event, he would have exposed the bases of the enclosed bombs so the fins could be attached without unpalletizing. Then the fins would have been well clear of the ground and would have had a better chance of dropping accurately onto the target.

Figure D-8 shows one-half of an ammunition shipload of ordnance destined for an aircraft carrier. This load was staged at Subic Bay in response to a request; it remained at this site (dump stored) at least 2 weeks (probably closer to a month). This occurred during the dry season, which is more thermally severe in the tropics. A closer examination by the author established that even the most technically sophisticated material was in the shipload represented by Figure D-8.

A stack of less technically sophisticated material is shown in Figure D-9. This is indicative of the attempt to care for weapons that must be dump stored because of either full facilities or no cover. Again, notice that the bulk density is great. Space is usually at a premium during the dump storage event.

Figure D-10 is an overview of the Chu Lai Marine Corps air facility in Vietnam. Chu Lai was started from scratch south of Da Nang for close infantry air support aircraft. The facility was extremely primitive when compared to any military air facility in the United

FIGURE D-7. Dump Storage Site Showing Damage to Fins of Palletized Bombs.

FIGURE D-8. Ammunition Staged at Subic Bay--Technically Sophisticated Material.

FIGURE D-9. Ammunition Stage at Subic Bay--Less Technically Sophisticated Material.

States. All supplies and material had to withstand the elements until pu[illegible] .o use. It was here at Chu Lai that over 100 Bullpup missiles were declared unserviceable when their extra heavy duty cardboard shipping containers "melted" at the onset of the rainy season. The reason was that bacteria and fungus had invaded the structure of the cardboard. Then, when the rains came, the cardboard inner structure had been weakened by "creature attack," and the boxes ended up a pile of amorphous pulp. The Bullpups themselves were found unharmed because the vapor barriers were still intact. Again, the designer of this shipping container had focused on a sturdy container that could be burned in the boilers of an aircraft carrier. Therefore, it would not take up valuable room on the aircraft carrier once the Bullpup missile had been expended, as would metal containers. However, in dump storage, bacteria, fungus and rain attacked the cardboard, to the detriment of the ordnance.

Figure D-11 is a close up of a portion of Figure D-10; it shows a typical scene at the Chu Lai Marine Corps air facility. U. S. Navy Construction Battalion 10 landed at Chu Lai in May 1965, to build an expeditionary airfield and base. Located 50 miles south of Da Nang, Chu Lai was home base for U.S. Marine jet attack and helicopter squadrons operating in support of ground forces in the Da Nang area. Over 9 million pounds of heavy equipment, building materials and supplies were landed by U.S. Navy Seventh Fleet LSTs to be used in the construction project.

Along with the impression of less than ideal fac'lities in the combat theatre, Figures D-12 and D-13 are included to convey the chaos of the combat (i.e. also dump storage) environment. Figure D-12 is typical of the preloading strategy that is striven for. When any material is preloaded, or staged, it is not necessarily used ^n that day. This figure also indicates that ordnance will get damaged if it has not been designed well.

Figure D-13, which is an amplification of the Figure D-12 situation, shows a typical combat situation.. In this case, ordnance is staged under the tropic sun on the deck of an ammunition ship in preparation for transferring the cargo to an aircraft carrier. During combat cond'tions, the aircraft carrier crews would pre-position the bombs in the flight deck gun tubs instead of putting them down in the magazines and then having to bring them back up for an air strike. The mitigating circumstance here is that the bombs would be expended in much less than a week's time.

FIGURE D-10. Chu Lai Marine Forward Air Base: Overview.

FIGURE D-11. Chu Lai Marine Corps Storage Facility; Typical Close up.

FIGURE D-12. Typical Preloading Strategy at Combat (Dump Storage) Area.

FIGURE D-13. Typical Combat Environment.

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2 Ogden Air Material Area, Hill Air Force Base
  Munitions Safety (1)
  Technical Library (1)
2 Rome Air Development Center, Griffiss Air Force Base
  Code RCRM (1)
  Technical Library (1)
1 Sacramento Air Material Area, McClellan Air Force Base
1 Warner Robins Air Material Area, Robins Air Force Base (Technical Library)
1 Armament/Munitions Requirements and Development (AMRAD) Committee (2C330, Pentagon)
1 Secretary of Defense (Defense Science Board)
2 DLA Administrative Support Center (Defense Material Specifications and Standards Office), Alexandria
  J. Allen (1)
  K. Green (1)
12 Defense Technical Information Center, Alexandria
3 Department of Defense Explosives Safety Board, Alexandria
  Air Force Member (1)
  Army Member (1)
  Navy Member (1)
1 Defense Test and Evaluation (Deputy Director, Test Facilities and Resources)
3 Deputy Under Secretary of Defense, Acquisition Management
  J. A. Mattino (1)
  Col. T. A. Musson (2)
1 Deputy Under Secretary of Defense, Research and Advanced Technology (Director, Engineering Technology)
2 AB BOFORS Ordnance, Sweden
  S. Blomgren (1)
  B. L. Persson (1)
1 BAC Dynamics Group, Hatfield Division, United Kingdom (W. B. Roberts)
3 BLS Associates, Ridgecrest, CA (H. Schafer)
1 Brigham Young University, Provo, UT (R. Ulrich)
1 Brownell Limited, Helena Works, United Kingdom (G. G. Hooper)
1 Brul and Kjaer GmbH, West Germany (K. Hansen)
4 Environmental Requirements Associates, Bothell, WA
  M. L. Lindsley (2)
  Technical Library (2)
1 Fraunhofer-Institut fur Treib-und Explosivestoffe, West Germany (H. Kugler)
1 GEC Avionics Limited, United Kingdom (H. Goldberg)